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ALTERNATIVE ENERGY SOURCES
• Solar and Hybrid Thermal Systems
• Solar Photovoltaic Systems
• Solar Radiation Measurement and Sun-tracking
• Geothermal Energy Applications
• Phase Change Materials (PCM) Applications
• Wind Energy
• Biotechnologies
• Hydrogen Energy
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F O R E W O R D

The Fourth International Scientific Conference "Alternative Energy Sources, Materials & Technologies AESMT'21" was held between 14^{th} and 15^{th} June 2021 in Ruse, Bulgaria. Representatives of 34 countries (Austria, Bulgaria, Chile, China, Cyprus, Egypt, France, Germany, Greece, Hungary, India, Iran, Iraq, Israel, Italy, Kazakhstan, Kosovo, Kuwait, Latvia, Lebanon, Lithuania, Macedonia, Nigeria, Norway, Portugal, Romania, Russia, Serbia, Spain, Tajikistan, Turkey, United Kingdom, and Yemen) sent their works to the conference. Selected reports (69 works) have been published as short papers in the proceeding of the conference.

It is my pleasure to be an editor of the presented short papers, which focus on new international scientific results in the field of Alternative Energy Sources, Materials and Technologies (Solar and Hybrid Thermal Systems, Solar Photovoltaic Systems, Solar Radiation Measurement and Sun-tracking, Geothermal Energy Applications, Phase Change Materials (PCM) Applications, Wind Energy, Biotechnologies, Hydrogen Energy, Ocean/ Tidal Energy, Energy Materials Science, Mechanical Engineering and Technologies, Electrical Engineering, Low-Carbon Technologies, Energy Efficiency).

Prof. Aleksandar Georgiev, PhD (European Polytechnic University, Pernik, Bulgaria)

Chair of the AESMT'21 conference

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ALTERNATIVE ENERGY SOURCES, Solar Radiation Measurement and Sun-tracking

Energetic analysis of single-axis trackers installed in a sloping terrain

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This paper analyses the change in performance for single-axis trackers aligned with the North-South axis as terrain slope increments. Such analysis is conducted for 10 different locations of various latitudes in the northern hemisphere. The results show gains in the absorbed radiation of over 10% for the highest latitude cities.

Keywords: Single-axis trackers, terrain slope, PV plants

INTRODUCTION

Single-axis trackers aligned with the North-South axis were designed for installation on flat terrain [1]. Considering that this kind of tracker is the most common solution for installing large solar projects [2], it is necessary to conduct a study of its performance in installations on sloping terrain.

This paper deals with the relationship between terrain slope and energy yield of a single-axis tracker aligned with the North-South axis. Said tracking geometry has been reviewed and simulations have been conducted for different locations and slopes of terrain.

EQUATIONS DEDUCTION

The annual incident irradiation on a tilted surface can be determined by the following equation:

$$H_t(n,\beta,\gamma) = \int_{T_R(n)}^{T_S(n)} I_t(n,T,\beta,\gamma)\, dT \qquad (1)$$

where:

$H_t(n,\beta,\gamma)$ - adjusted total solar irradiation on a tilted surface under real weather conditions, Wh/m²;

$I_t(n,T,\beta,\gamma)$ - adjusted hourly distribution of total solar irradiance on a tilted surface under real weather conditions, W/m²;

n - day of the year;

β - tilt angle, rad;

γ - azimuth angle, rad;

T - solar time, h;

T_R - sunrise solar time, h;

T_S - sunset solar time, h.

The total solar irradiance can be decomposed into three components and can be calculated as:

$$I_t(n,T,\beta,\gamma) = I_{bh}(n,T)\frac{cos\theta}{cos\theta_z} + I_{dh}(n,T)\frac{1+cos\beta}{2} + \rho_g\left(I_{bh}(n,T) + I_{dh}(n,T)\right)\frac{1-cos\beta}{2} \qquad (2)$$

where:

$I_t(n,T,\beta,\gamma)$ - adjusted hourly distribution of total solar irradiance on a tilted surface under real weather conditions, W/m²;

$I_{bh}(n,T)$ - adjusted hourly distribution of beam solar irradiance on a horizontal surface under real weather conditions, W/m²;

$I_{dh}(n,T)$ - adjusted hourly distribution of the diffuse horizontal solar irradiance under real weather conditions, W/m²;

θ_z - zenith angle of the Sun, rad;

θ - incident angle, rad;

β - tilt angle, rad;

ρ_g - ground reflectance, dimensionless.

The parameters θ and β of the equation (2) are deducted from Fig.1. The incident angle can be calculated:

$$cos\theta = \frac{\overline{n}_s.\overline{n}_p}{|\overline{n}_s|.|\overline{n}_p|} \qquad (3)$$

where:

$\overline{n}_s$ - solar vector.

$\overline{n}_p$ - vector normal to the collector surface.

$$\cos\theta = \cos\delta\sqrt{sin^2\omega + (\cos\omega\cos(\lambda - A) + \tan\delta\sin(\lambda - A))^2} \quad (4)$$

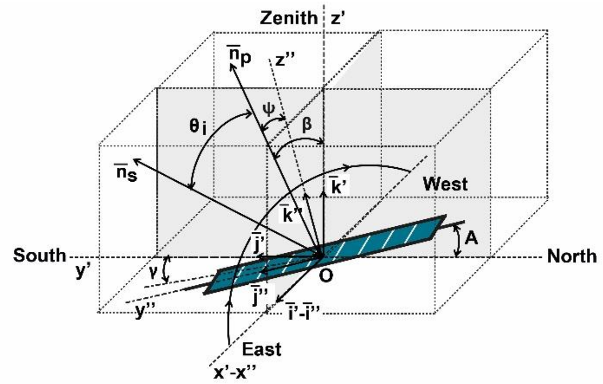

Fig.1. Solar geometry used in the current study

Tilt angle can be calculated:

$$\beta = arccos\left[\frac{\cos A\left(\cos\omega\cos\delta\cos(\lambda - A) + \sin\delta\sin(\lambda - A)\right)}{\cos\theta}\right] \quad (5)$$

RESULTS AND DISCUSSIONS

A custom code has been developed for the software solution Mathematica in order to obtain all three components of the total solar irradiance. The beam and diffuse solar irradiance on a horizontal surface under real weather conditions have been calculated with the method proposed by [3]. Tab.1 shows, for the 10 cities under study, the annual solar irradiation for both the minimum and maximum possible terrain slope.

When the terrain slope is null, the annual energy has the smallest value. For all cities, as terrain slope increases, so does the annual energy, though such effect is less notorious in lower latitudes.

Fig.2 shows of annual energy in the cities under study. The values are as a percentage of energy, with respect to the null slope (A=0 (º)) situation.

Table 1. Annual solar irradiation (MWh/m²)

Cities	Terrain slope (º)	
	0	λ
Medellin (Colombia)	2.1340	2.1371
Bangkok (Thailand)	2.1505	2.1788
Morelia (Mexico)	2.6826	2.7607
Karachi (Pakistan)	2.5880	2.7039
Cairo (Egypt)	2.7238	2.8585
Almeria (Spain)	2.5004	2.6998
Toronto (Canada)	1.6216	1.7389
Wien (Austria)	1.4971	1.6186
Hamburg (Germany)	1.3028	1.4392
Helsinki (Finland)	1.1926	1.3203

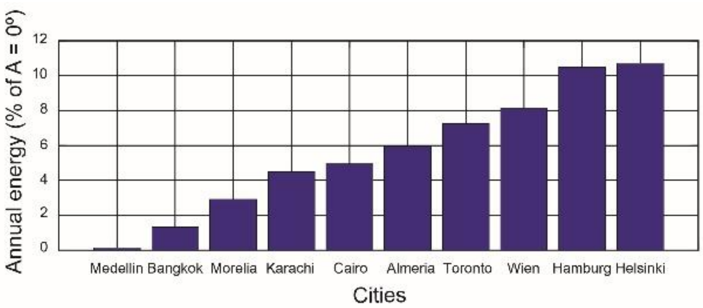

Fig.2. Comparison annual energy

The percentage of the energy gains associated with terrain slope, referenced to flat terrain, ranges from 0.14% for cities of low latitude, up to 10.71% for places closer to the Poles.

CONCLUSIONS

Terrain slope has a remarkable influence on the energy yield of single-axis trackers aligned with the North-South axis. This phenomenon is more notable as latitude increases, resulting in gains of more than 10% in energy production in the best situations.

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