INFLUENCE OF TILT ANGLE ON PV ELECTRICITY GENERATION IN TARGU JIU AREA. PART 1 - MAIN PARAMETERS

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ABSTRACT: *The most important features affecting the generated PV output are pointed out in the paper. The results obtained by other researchers regarding the optimal value of the installation angles of photovoltaic panels are summarized.*

KEY WORDS: PV panel, tilt angle.

1. INTRODUCTION

In recent years, photovoltaic (PV) systems have developed very quickly. Only in 2016, 75 GW of new PV capacity were installed worldwide [1], of which 34.54 GW in China [2]. At the end of 2016, the global photovoltaic power capacity worldwide was more than 303 GW [1].

The most important features affecting the generated PV output are [3]: (1) the angle of inclination and (2) the azimuth angle of the photovoltaic modules, (3) the installed capacity and (4) the efficiency of photovoltaic panels

The solar panel efficiency quantifies a solar panel's ability to convert sunlight into electricity. In the same operating conditions, the more efficient panel will produce more electricity than the less efficient panel.

The most efficient solar panels on the market today have efficiency ratings as high as 22.2%**,** whereas the majority of panels range from 15% to 17% efficiency rating. The most efficient solar panel brand available on the market is SunPower, followed by LG and Panasonic [4].

The more efficient panels are more expensive and the choice of PV panel type depends, ultimately, on the payback period.

Once the PV panel type is chosen, when designing installations with fixed photovoltaic panels, the installation angles are the most important parameters to be considered. Installation angles for photovoltaic systems refer to the tilt angle and azimuth angle, which are chosen to achieve the maximum PV power over the year.

2. SOLAR ANGLES

A part of the sun radiation falling on the earth are absorbed and reflected back by the atmosphere and the clouds. Some angles form between the sunlight falling on the earth and the surfaces. The position of the sun at different periods is determined by the solar angles.

Moreover, solar angles are used to track the movement of the sun in a day. The rotation of the sun varies depending on the latitude and longitude of the location. Therefore, the solar angles will be different for the locations at different latitude and longitude during the same period. So, the solar angles must be known to determine the position of the sun [5].

Declination angle is the angle between the sun lights and equator plane. Declination angle occur due to 23.45 degree angle between earth's rotational angle and the orbital plane.

Declination angle is shown in Figure 1.
The declination angle is calculated by equation (1).

$$\delta = 23{,}45 sin\left(360 \cdot \frac{284 + n}{365}\right) \quad (1)$$

where n represents the day of the year and 1st January is accepted as the start [16, 18, 20,].

The basic solar angles existed on the earth's surface are shown in Figure 2.
Zenith angle (θ_z) is the angle between the line to the sun and the vertical axis.
Zenith angle is calculated depending on the other angles [6].

$$cos\theta_z = cos\delta \cdot cos\varphi \cdot cos\varpi + sin\delta \cdot sin\varphi \quad (2)$$

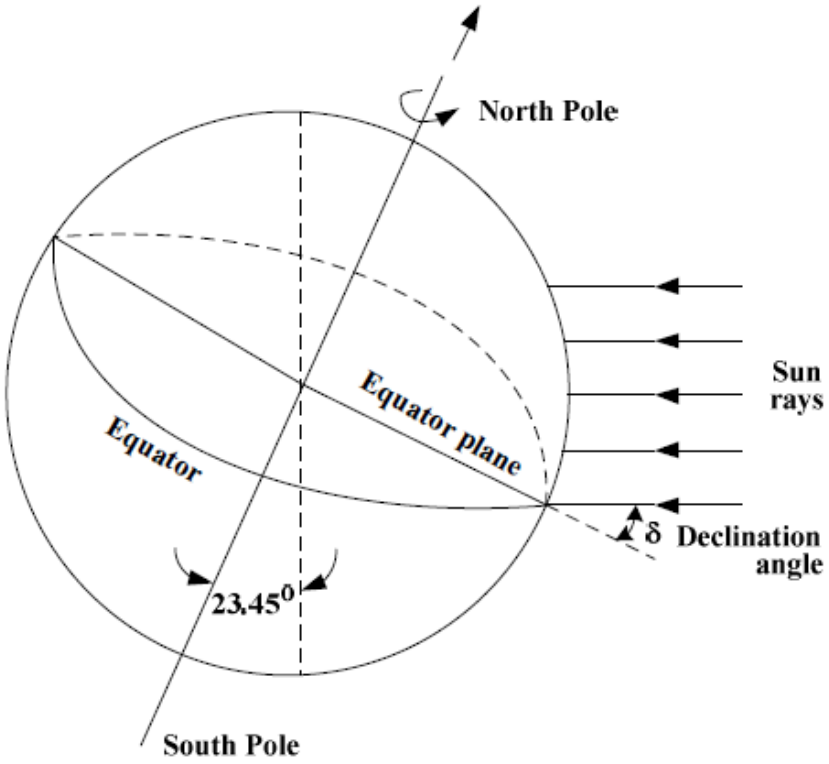

Fig.1. Dclination angle

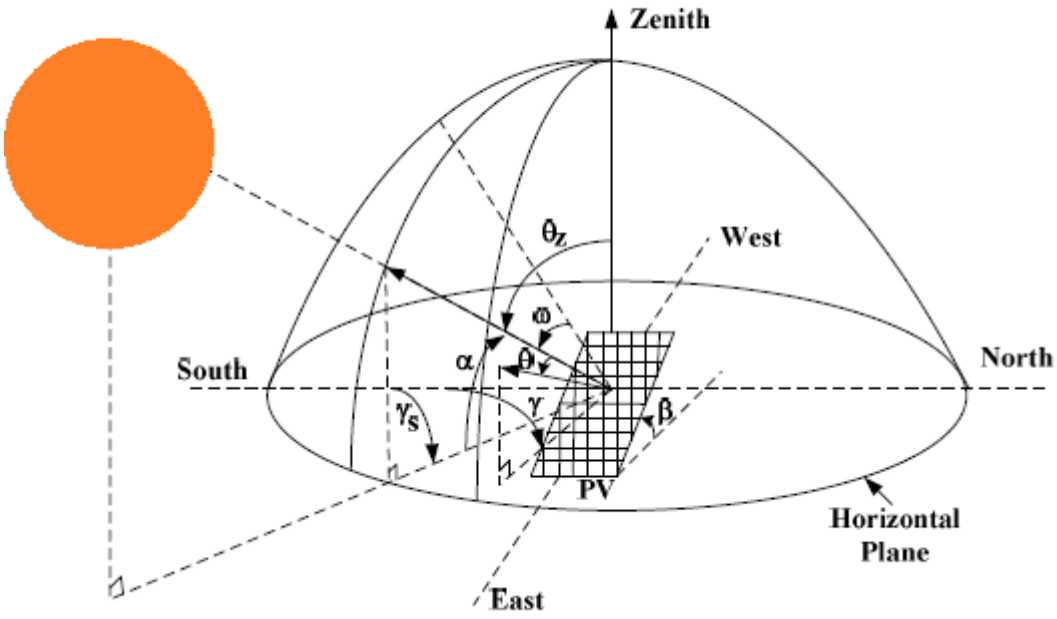

Fig.2. Solar angles

Solar elevation angle (α) is the angle between the line to the sun and the horizontal plane. This angle is the complement of the zenith angle. Elevation angle is calculated by the equation (3).

$$\alpha = 90 - \theta_z \quad (3)$$

Solar azimuth angle (γ_S) is the angle between the north or south position of the sun and the direct solar radiation. This angle is assumed to be (-) from south to east and to be (+) from south to west. Azimuth angle is calculated by the equation (4).

$$\gamma_S = cos^{-1}\frac{sin\alpha \cdot sin\phi - sin\delta}{cos\alpha \cdot cos\phi} \quad (4)$$

Incidence angle (θ) is the angle between the radiation falling on the surface directly and the normal of that surface. The incidence and tilt angles are shown in Figure 3.

Incidence angle is used in the design of solar energy systems.

Incidence angle is calculated by the equation (5) [7].

$$\theta = cos^{-1}(cos\delta \cdot cos\varphi \cdot cos\varpi + sin\delta \cdot sin\varphi) \quad (5)$$

Tilt angle (β) is the angle between the panels and the horizontal plane. This angle is south oriented in the Northern Hemisphere and north oriented in the Southern Hemisphere. Tilt angle varies between 0 and 180°. When a plane is rotated about horizontal east-west axis with a single daily adjustment, the tilt angle of the surface will be fixed for each day and is calculated by the equation (6).

$$\beta = |\varphi - \delta| \quad (6)$$

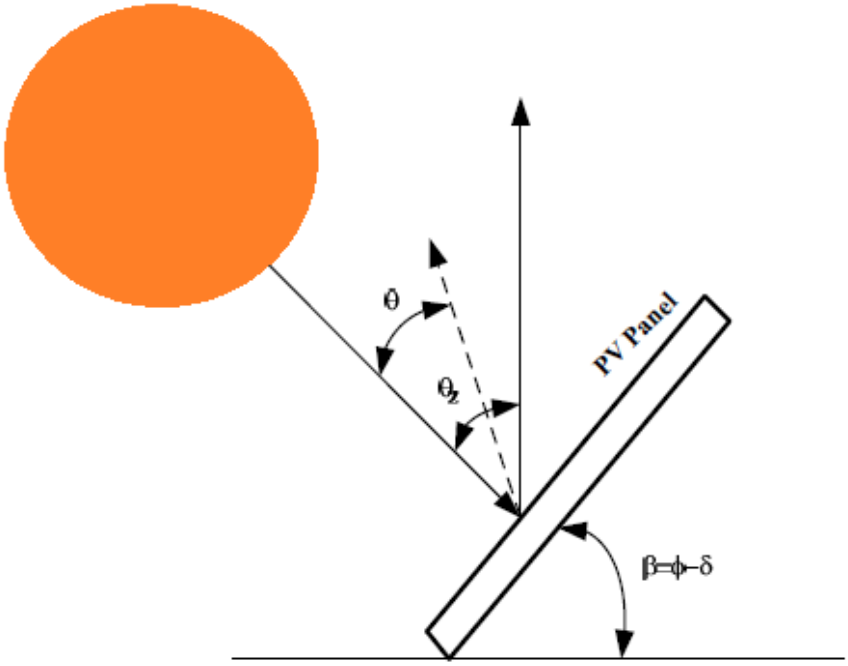

Fig.3. Incidence and tilt angles

3. RELATED WORK

Several authors determined relationships between the optimal tilt angle and latitude, relationships that are generally used to determine the optimal tilt angles used by solar system installers for most locations [8]. These methods provide simple and approximate values for the tilt angle; however, the optimal angle for a particular location should be determined using the measured values of the solar radiation at that location.

The proposed relationship for the optimal tilt angle does not take into account factors that affect solar radiation, such as altitude above sea level and sunrise, so these relationships do not provide accurate results for cloudy regions.

It is difficult to determine their precision for any place, but these relationships are mostly used by the photovoltaic industry to install the solar system. It is recommended that the tilt angles in winter seasons be approximately 5^o greater than the usual recommended angle of inclination [9]. In the winter season, solar radiation is mostly incident at noon, so the panel should be more inclined to collect maximum solar energy throughout the day. In the summer season, the sun moves down the sky in the morning and in the evening, so it is necessary to less incline to collect the maximum solar radiation.

Calculation of the tilt angle to maximize solar radiation on inclined surfaces can generally be made for locations between 5^o and 40^o N latitude, with a sunny climate dominated by the direct radiation component. Areas beyond 45^o N receive a higher amount of diffuse radiation due to the clouds cover. Therefore, the methods of selecting the angle of inclination as exclusive direct radiation are inappropriate because other atmospheric conditions are not taken into account.

Armstrong and Hurley [8] have developed a methodology to determine the optimal tilt angle for frequently cloudy locations using monthly sunrise data. In cloudy conditions, it is important to distinguish between direct and diffuse radiation for a particular location to calculate the optimal tilt angle, so the Perez model is useful for calculating diffuse radiation falling on the solar panel.

3. CONCLUSION

To increase the energy generated by photovoltaic panels, they must be inclined towards the sun. The optimal angle varies throughout the year, depending on the seasons and location of the PV system.

At noon, sunshine is at the highest level, and PV panels generate the most power. In the northern hemisphere, the sun is set south at noon.

Therefore, in order to get the best results from photovoltaic panels, they must face the south at an optimal angle so that the panel receives as much sunlight as possible at this time.

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