Performance analysis of photovoltaic generation among three typical sunlight collecting method in the city of Chengde

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Abstract

Detailed performance analysis of photovoltaic generation among three typical sunlight collecting method was carried in Chengde city. The effects of the date and tilt angle on the generating efficiency of photovoltaic system were investigated. Furthermore, the instantaneous efficiency enhancements of the output power generated by a photovoltaic panel mounted on a single and dual-axis tracking system compare to a fixed panel were estimated. The result shows: the monthly enhancements of the gain are more remarkable for two critical periods surrounding the summer and the winter solstice dates. For the single-axis tracking method, it reaches the value of 16.72% and 14.23% in the summer and winter solstice periods, respectively. For the dual-axis tracking method, this gain reaches the value of 37.5% and 31.8% respectively in the summer and the winter solstice days, respectively.

Keywords

Photovoltaic; Solar Tracking; Optimal Angle; Efficiency Enhancement; Chengde.

1. Introduction

Renewable energy resources have big potential and can satisfy world energy demand, which can enhance diversity in energy supply markets, secure long-term sustainable energy supply, and reduce local and global atmospheric emissions[1]. The solar energy is one of the important renewable energy, which can be captured anywhere and can be directly converted into electric power through photovoltaic panels[2], it also allow the production of electricity using photovoltaic cells that convert solar irradiation into electricity.

Firstly, the photovoltaic panels was designed as a type of technology to be used for external space applications[3]. Now, the photovoltaic applications have been harnessed in various areas such as water pumping, rural electrification, remote meteorological stations, maritime and railway crossing, production of hydrogen, grid connection systems, refrigeration, low power rural industrial applications, etc.

A photovoltaic module is composed of many solar cells. The output power of a photovoltaic module is mainly concerned with two factors, i.e. cell temperature and solar radiation incident on it. The solar radiation intensity on a panel is affected by the installation azimuth and tilt angle, as both angles influence the incident angle of sunlight on it. The optimal angles vary with conditions such as the geographic latitude, climate, atmospheric composition, utilization period and so forth. It is known that the optimum value of yearly maximum output energy could be obtained from photovoltaic modules oriented facing south and the optimum tilt angle is equal to the local latitude[4].

In this paper, the factors effect the photovoltaic output power are analyzed in detailed. Furthermore, many factors that affect the instantaneous PV production are analyzed for specific days in different situations using the case study of Chengde city. Also, the extra amount of output power generated by a single-axis tracked panel compare to fixed panel are estimated in this paper. Finally, the gains made by a dual-axis tracked panel are evaluated.

2. Photovoltaic Generation

The photovoltaic generation is mainly dependent on the global incident radiation and the photovoltaic cell temperature.

2.1 Photovoltaic Cell Temperature

It is well understand that the photovoltaic cell temperature has an important effect on the photovoltaic output power. The temperature can be the same as the ambient temperature in the night but it can go over the ambient temperature by 30°C or more in full sun. Hence, it is necessary to solve the photovoltaic cell temperature in order to account for this effect. Therefore, we have to begin by establishing the energy balance equation between the solar energy absorbed by the photovoltaic array, and the electrical output plus the heat transfer to the surroundings, which can be written as[4]:

$$\tau\alpha G_T = \eta_C G_T + U_L\left(T_C - T_a\right) \quad (1)$$

where τ, α, G_T, η_C, U_L and T_a are respectively the solar transmittance of the photovoltaic array, the solar absorptance of the photovoltaic array, the global radiation striking the photovoltaic array, the electrical conversion efficiency of the photovoltaic array, the coefficient of heat transfer to the surroundings and the ambient temperature. According to the above equation, the photovoltaic cell temperature also can be shown as follows:

$$T_C = T_a + G_T\left(\frac{\tau\alpha}{U_L}\right)\left(1 - \frac{\eta_C}{\tau\alpha}\right) \quad (2)$$

To estimate the value of $\left(\tau\alpha/U_L\right)$, the nominal operating cell temperature (NOCT) is induced, which is defined as the cell temperature that results at an incident radiation of 0.8 kw/m^2, an ambient temperature of 20°C, and no load operation (meaning $\eta_C = 0$) average wind speed equal to 1m/s[5]. Substitute these values into the equation (2) and solve it for $\left(\tau\alpha/U_L\right)$:

$$\frac{\tau\alpha}{U_L} = \frac{T_{C,NOCT} - T_{a,NOCT}}{G_{T,NOCT}} \quad (3)$$

If $\left(\tau\alpha/U_L\right)$ is a constant value, and suppose that the photovoltaic array always operates at its maximum power point η_{mp}. Meanwhile, η_{mp} depends on the cell temperature T_C. If assume that the efficiency varies linearly with temperature according to the following equation:

$$\eta_{mp} = \eta_{mp,stc}\left[1 + \alpha_p\left(T_C - T_{C,stc}\right)\right] \quad (4)$$

where η_{mp}, α_p and $T_{C,stc}$ are respectively the maximum power point efficiency under standard test conditions (radiation 1 kw/m^2, cell temperature 25°C, no wind), the temperature coefficient of power and the cell temperature under standard test conditions. We note here that the temperature coefficient of power $\left(\alpha_p\right)$ is negative which means that the efficiency of the photovoltaic array decreases with increasing the cell temperature.

Finally, the cell temperature becomes:

$$T_C = \frac{T_a + \left(T_{C,NOCT} - T_{a,NOCT}\right)\left(G_S/G_{S,NOCT}\right)\left[1 - \left(\eta_{mp,stc}/\tau\alpha\right)\left(1 - JT_{C,stc}\right)\right]}{1 + \left(T_{C,NOCT} - T_{a,NOCT}\right)\left(G_S/G_{S,NOCT}\right)\left(\eta_{mp,stc}/\tau\alpha\right)} \quad (5)$$

2.2 Photovoltaic Output Power

The assessment of the photovoltaic output power was the interest of many authors. Thus, a several models[6.7] have been developed in order to evaluate all photovoltaic characteristics. One of the simplest model to predict the photovoltaic array output power is used in this study, which assumes that:

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\bar{G}_T}{\bar{G}_{T,stc}} \right) \left[1 + \alpha_p \left(T_C - T_{C,stc} \right) \right] \quad (6)$$

where Y_{PV} , f_{PV} , $\bar{G}_{T,stc}$, α_p , T_C , $T_{C,stc}$,are respectively the rated capacity of the photovoltaic array, the photovoltaic derating factor (it is used to account for such factors as shading, snow cover, aging, and so forth), the incident radiation at standard test conditions, the temperature coefficient of power, the photovoltaic cell temperature in the current time step and finally the photovoltaic cell temperature under standard test conditions. The global radiation on tilted surface $\bar{G}_T$ can be obtained by the HDKR method presented by Maatallah[8].

3. Results

This study is related to the city of Chendge which is situated on the north-east of China, about 200km far from the capital Beijing. The latitude and longitude of this town are respectively 40.90° N and 117.96° E and an altitude of 310m above sea level. It should be noted also that all simulations in this work are computed with a time step equal to ((1/12) h).

3.1 Effect of Date on the Instantaneous Photovoltaic Output Power

In order to study the dependence of the photovoltaic production with the effect of date throughout the whole year, four extreme days of the year are considered, i.e. vernal and autumnal equinox, and summer and winter solstice days. The results are carried out for a photovoltaic module oriented straight to the south by 0° Azimuth angle as well as a tilt angle equal to the latitude of Chengde (40.90° N).

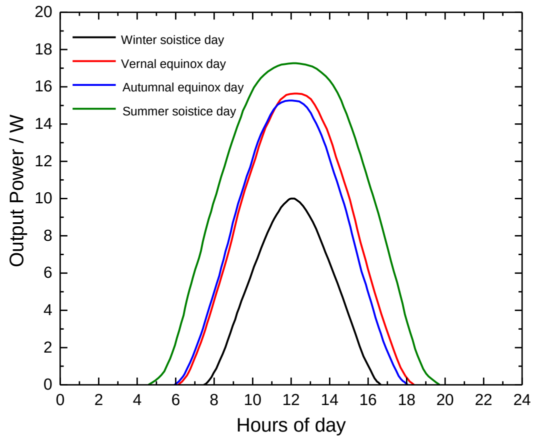

Fig. 1 Instantaneous photovoltaic output power in Chengde

The simulated results are illustrated in Fig. 1. Due to the difference in the length of the day between summer and winter, it can be observed that the photovoltaic panel is generating electricity slightly for less than 10h at the winter solstice day and to slightly for more than 14h at the summer solstice day. During a day, the photovoltaic output power will begin to increase from sunrise to midday then decline until sunset. It is worth notice that the photovoltaic output power maximum points are different slightly among each days. This can be related to how high in the sky the sun appears. The operating hours of photovoltaic system in winter is shorter than in spring (or autumn) because the short sunshine time in winter compared to the vernal or autumn periods.

3.2 Effect of Tilt Angle on the Instantaneous Photovoltaic Output Power

The tilt angle with the horizontal is an important parameter that affect the performance of a photovoltaic system. This is because of the fact that the variation of tilt angle changes the amount of the solar radiation reaching the photovoltaic panel. Fig. 4 shows the instantaneous photovoltaic output power for different inclinations in Chengde during the summer solstice day.

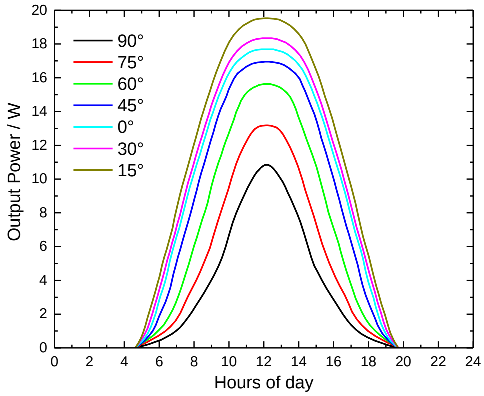

Fig. 4 Instantaneous photovoltaic output power with different inclinations during the summer solstice day in Chengde

It is shown that the tilt angle has a very dramatically effect on the instantaneous photovoltaic production during the summer solstice day[9]. It can be seen that the solar radiation incidence angle on photovoltaic array is the key factor effect the output power, a optimal tilt angle can make the photovoltaic array almost perpendicular to solar ray at the midday and nearly obtain 80% more solar energy than the status with the tilt angle of 90° .

3.3 Monthly Optimal Tilt Angles for A South Facing Panel

In order to enhance the photovoltaic output power without tracking system, Gunerhan and Hepbasli[10] recommends that solar collector systems should be adjusted with the optimal angle every month. Based on the simulation the monthly optimal tilt angle for a photovoltaic array facing the south in the Chengde city is shown in Tab.1. It can be seen that the optimal angles vary from 17.6° in June to 64.1° in December. In the first six months of a year, the optimal tilt angle has the trend to decrease from 62.1° in January to 17.6° in June. However, in the second half of the year the optimal tilt angle decrease till 64.1° at the end of the year. This monthly optimal tilt angle tendency is in good agreement with the former researcher[4]. In the city of Chengde and also including other mid-latitude countries north of the equator, the sun's daily track is an arc through the southern sky. The sun's greatest height above the horizon occurs at midday, and how high the sun can be depends on the season of the year, it is the highest in mid-summer (June), and the lowest in mid-winter (December) .

Tab. 1 Monthly optimal tilt angles in Chengde

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Optimal slop	62.1	53.7	42.9	30.9	22.2	17.6	19.5	26.9	38.1	49.5	59.4	64.1

3.4 Comparison Between the Output Power Generated by A Traditional Fixed and Single-Axis Tracked Panel

A comparison of monthly output solar energy between fixed and single-axis tracked photovoltaic module is illustrated in Fig. 3. It is shown that the optimal yearly tilt angle (40.9°) is used for the fixed panel and the optimal monthly tilt angles are used for the single-axis tracked system. It can be observed that the tracked panel generates more output power than the fixed panel because of its smaller incidence angle of sunlight. It can be seen from the picture that the gain from the tracked panel is more noticeable for two critical periods. The first period corresponds to the summer period, in which the gain reveals its highest value nearly 2.61 kwh about 16.72% more than the energy generated by a fixed photovoltaic collector, and the other one within the winter period, in which the gain from the single-axis tracked panel nearly 1.53 kwh about 14.23% more than the energy generated by a fixed photovoltaic panel. Throughout the other periods, there are no significant difference between fixed and single-axis tracked panel.

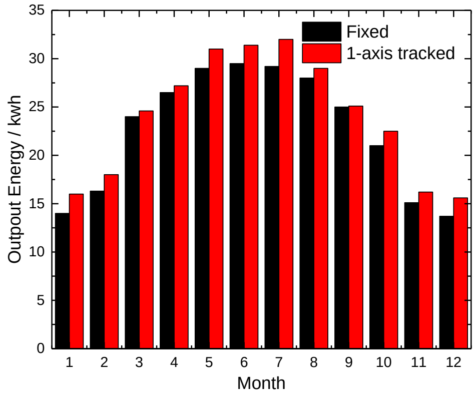

Fig. 5 Monthly photovoltaic output energy generated by a fixed and a single-axistracked panel in Chengde

3.5 Comparison Between the Output Power Generated by A Traditional Fixed and Dual-Axis Tracked Panel

Tab. 2 shows the PV output power generated by fixed module with the yearly optimal tilt angle (40.9°) facing the south and a dual axis tracked panel during the vernal equinox, summer solstice, autumnal equinox, and winter solstice days respectively in Chendge city. It is found that the dual-axis tracked panel obtains more energy than the fixed panel because of its optimal incidence angle of sunlight during the day. Similar results was proposed by Kacira et al.[11] who studied the performance of PV modules mounted on a dual-axis solar tracker. They concluded that the obtain in the daily energy generation can reach to 34.6%. In this paper, the increment made by the dual-axis tracked PV system during the summer and winter solstice days reaches respectively 1.03 kwh and 0.57 kwh, which made by the dual-axis tracked PV system correspond to a gain of 37.5% and 31.8% respectively more in the summer and winter solstice days compared to the traditionally fixed panel.

Tab. 2 Instantaneous photovoltaic output energy generated by a fixed and a dual-axis tracked panel in Chengde

Date	vernal equinox	summer solstice	autumnal equinox	winter solstice
Fixed	0.81	1.03	0.83	0.57
2-axis tracked	0.93	1.42	0.94	0.75

4. Conclusion

An overview on research works on solar radiation basics and photovoltaic generation has been presented. The method for solving the output energy of a PV system have been presented. A detail performance analysis of fixed, single and dual-axis tracking photovoltaic panel have been investigated. This study can be a theory evidence for PV system assessment and planning for PV projects. Based on this study in Chengde, some important concluding remarks are as follows:

• The gain by an one-axis tracking panel relative to a fixed panel are more noticeable for two periods: the date near summer and winter solstice days. It obtains the value of 16.72% and 14.23% more in the summer and winter solstice periods, respectively.

• A dual-axis tracking system can be induced to further optimize the solar systems. The result shows that, compare to the fixed panel, the dual-axis tracking panel can gain 37.5% and 31.8% respectively more solar energy in the winter and summer solstice days.

• This study provide a guide to the choice of the optimal tilt and azimuths angles for fixed and tracked panel mounted on single and dual-axis photovoltaic systems used in the city of Chengde.

Acknowledgements

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