

Study on Seasonal Adjustment of Solar PV Tilt Angle around the North of 45th Parallel

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Abstract: The tilt angle of the small scale existing solar power plants is 60 degree and it is 45 degree for the megawatts (MW) class solar power plant in Mongolia. However, the PV module which is installed with 45 degree accumulates lots of snow during the winter. Currently, all solar PV systems installed in Mongolia are fixed the direction and tilt angles. According to the previous research result, the tilt angle of those systems was not suitable for using especially in the winter. The PV module which is installed with 60 degree does not accumulates snow even during the autumn and spring. According to the National Aeronautics and Space Administration (NASA) solar radiation database, solar irradiance for equator facing is largest at 32-degree tilted angle during the summer, 47-degree during the spring and autumn, at 62-degree during the winter. The results of this paper show, the tilt angle of the PV module should be adjusted at least twice a year. For instance, the tilt angle will be adjusted at the 32-degree from 15th March to 24th August, at the 62-degree from 25th August to 15th March. In this case, the annual total energy output will be increased up to 30% than present production.

Key words: PV module, array, tilt angle.

1. Introduction

There are several megawatts (MW) class solar power plants in Mongolia. The tilt angle of the PV array of those power plants is fixed at the 45 degree. During the winter in Mongolia, the dried snow is small like a dust fall. The snow will be accumulated on the 45-degree inclined surface of the PV module. It is necessary to remove the accumulated snow layer carefully to avoid any damage on the module surfaces. If the accumulated snow layer is not removed, the energy output by the PV system will be reduced to 70% [1]. If it can adjust the tilt angle at the 60 degree during the winter, the dry snow is not accumulated on the PV module surface and it increases the energy output during the winter season. There are existing small-scale solar PV systems which installed 60-degree tilted angle for radio relay stations. All

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those PV modules are not covered by snow during winter season.

The purpose of this research is to determine the optimum tilt angle in operation in subarctic climate. In this study, operational data of 0.5 MW solar PV systems that installed in Ulaanbaatar are analyzed. The relation between energy output and ambient temperature is clarified based on the actual operational data.

Energy output from the solar PV system in different tilt angle is calculated. Considering both of cooling effects by ambient temperature and estimation of energy output by different tilting angles, suitable tilting angles of the PV modules are simulated. Fig. 1 shows solar PV system covered by snow during winter in Ulaanbaatar. The Ulaanbaatar is located at 47 ° N. Fig. 2 shows the location of Ulaanbaatar.

In the area, sunshine hours are very short in winter season, however power demand increases in the winter.

2. Solar Power Plants in Mongolia

The total installed capacity of the solar PV system



Fig. 1 Solar PV system covered by snow.



Fig. 2 The Ulaanbaatar in the subarctic climate.

reached already 50 MW. It is almost 5% of all power installations in Mongolia.

The first grid-connected solar power plant in Mongolia was 0.5 MW in Ulaanbaatar, and the solar PV system was constructed under the grant pilot project by Japanese government. The plant was commissioned on September 2012 and connected to the central energy system of Mongolia [2].

In Darkhan city, 10 MW solar PV plant was installed and commissioned in 2016. It is connected to the grid with 110 kV power transmission line to the 220/110/35 kV Darkhan substation. Currently, several MW-class solar PV plant projects are being planned and constructed.

As for small scale solar PV system, the "100,000 SOLAR GER" project by Mongolian Government was carried out between 2000 and 2012. The objective of the project is to establish micro solar electricity generation system at Nomadic families and it could electrify 100,146 families in off-grid area. The total capacity of those micro systems was reached to 5 MW in minimum.

Fig. 3 shows energy output from solar PV from 2013 to 2018.



Fig. 3 Energy output from solar power plants in Mongolia.

3. Annual Energy Output

The annual total energy consumption of Mongolia was 8,308.3 million kWh in 2018. The annual energy production was 6,624.8 million kWh and the annual power import was 1,683.6 million kWh or 20% of the total consumption.

The coal fired thermal power plants produced 6,152.4 million kWh or 92.9% of total production in 2018.

The 468.7 million kWh or 7.1% was produced by using renewable energy sources such as wind power plant (72%), solar power plant (11%), and hydro power plant (17%) in 2018 [3].

The price of electricity which is produced with the coal fired power plant is 0.01~0.02 USD/kWh and the average price of the power imported is 0.025 USD/kWh, while the price of electricity from the solar power is 0.09~0.11 USD/kWh [4].

The feed in tariff for renewable energy source in Mongolia is $19.00 \overline{F}$ /kWh or 0.008 USD/kWh [5].

4. Estimation of Energy Output

The solar tracking system is the most popular method to increase the total energy output from the solar power plant. In modern practice active and passive solar tracking systems are being introduced in many cases. However, the average cost of the active tracking system is expansive as 3,500.00 to 7,000.00 USD/kW. Therefore, solar tracking system is not attached to the MW-class solar PV system in Mongolia.

According to the latitude of Ulaanbaatar, the tilt angle of the PV module has to be adjusted at 47 degrees facing to the South.

In the study, operational data of solar PV system which is installed at Ulaanbaatar were used for the analysis. For the estimation of the energy output from different tilt angle, the 47 degrees (angle of latitude) and 32 degrees and 62 degrees (plus and minus 15 degrees) are compared.

4.1 Temperature Coefficient

Ulaanbaatar is located at the 47° N and categorized in steppe climate. Fig. 4 shows annual daily ambient temperature of Ulaanbaatar. In the winter, the diurnal ambient temperature is minus 40 degrees. And in the summer, the ambient temperature becomes around 30 degrees. Energy conversion efficiency of solar PV varies with temperature and the efficiency increases with decreases of temperature.

Fig. 5 shows energy output that recorded 1.0 kWh/m^2 of solar irradiation at different ambient temperature. The figure shows average energy output decreases with increase of ambient temperature. There is a proportional relationship between ambient temperature and energy output by solar PV system.

The temperature coefficient (K_{PT}) is calculated with the following Eqs. (1) and (2).

$$K_{\rm PT} = 1 + \alpha P_{\rm max}(T_{\rm CR} - 25)/100$$
 (1)

where, αP_{max} : temperature coefficient of max. power (%/°C), -0.46 for KD135GH-2PU.

$$_{\rm CR} = T_{\rm AV} + \Delta T \tag{2}$$

where:

 $T_{\rm CR}$: average temperature on the PV module surface, °C;

 $T_{\rm AV}$: monthly average ambient temperature, °C;

 ΔT : grouse of the temperature on the PV module surface, °C.

In the study, temperature coefficient at Ulaanbaatar was calculated 0.84 in summer and 1.22 in winter as shown in Table 1.



Fig. 4 Ambient temperature in Ulaanbaatar area.



Fig. 5 Power value which is related with ambient temperature of 1 kWh/m² inclined solar radiation.

Table 1Temperature coefficient (K_{PT}) in the Ulaanbaatararea.

Month	Jan.	Feb.	March	Apr.	May	June
K _{PT}	1.22	1.22	1.22	1.1	1	0.9
Month	July	Aug	Sep	Oct	Nov	Dec
$K_{\rm PT}$	0.9	1	1.1	1.1	1.22	1.22

4.2 Inclined Insolatioan

Fig. 6 shows the results of estimated monthly energy output from 0.5 MW solar PV system in different tilting angle of 32 degrees, 47 degrees and 62 degrees. The results show there is a seasonal difference on energy production by different tilt angles. Energy output of 62-degree tilt angle is large in winter season; on the contrary, energy output of 32-degree tilt angle is large in summer season. And in other seasons, energy output of 47-degree is largest. The number of days and seasons of prevailing inclined insolation is summarized as follows.



Fig. 6 Comparison of annual energy output.



Fig. 7 Comparison of annual energy output.

(1) Energy output from 62 degrees is largest from
5th October to 9th February (124 days);

(2) Energy output from 32 degrees is largest from 15th March to 24th August (165 days);

(3) Energy output from 47 degrees is largest except the days mentioned above (76 days).

On the basis of the above results, optimum seasonal adjustment of solar PV tilt angle was decided as follows:

- 62 degrees: from 25th August to 14th March;
- 32 degrees: from 15th March to 24th August.

4.3 Optimum Operation

Annual energy output was estimated based on the tilt angle and temperature coefficient. The result of comparison is shown in Fig. 7. Comparing the both operations, energy output from the combined 32 and 62 degrees is increased over 30%. The energy output was calculated by following Eq. (3):

$$E = P_{\rm SI} \times P \times N \times \eta_P \times \eta_I \times \eta_C \times \eta_T / P_0 \qquad (3)$$

where:

 $P_{\rm SI}$: solar irradiation, kWh/m²/day;

P: capacity of the PV array or power plant, kW;

N: number of days;

 η_{P} : coefficient of pollution;

- η*I*: coefficient of inverter;
- η_C : coefficient of cable;
- η *T*: coefficient of temperature;

 $P_0: 1,000 \text{ W/m}^2.$

5. Conclusions

Annual energy production at tilted angle 60 degrees is less than that of 45 degrees. However, considering the operation during winter season, at 60-degree tilted angle PV array is not covered by snow. In addition to that, by the 60-degree tilted angle, reflection from the snow-covered ground is expected to increase the total energy production. On the contrary, energy production reduces to 70% by the snow at 45 degrees.

In this study, seasonal energy production from different tilted angles at 32, 47 and 62 degrees was compared. In the summer, energy production was large at 32 degrees tilted angle. In autumn and spring, it was large at the 47 degrees, and in winter largest energy production was at the 62 degrees in the Ulaanbaatar area.

In Mongolia, seasonal differences of ambient temperature are so large therefore differences of the temperature coefficient have to be considered. The temperature coefficient was calculated 1.22 during cold season and 0.9 during warm season.

On the result, the energy output can be increased over 30%, if the tilt angle is adjusted at 62 degrees during cold and at 32 degrees during warm season.

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