Solar Technology and Resource Evaluation in the Gobi Desert of Mongolia

ゴビ砂漠で10年以上続けられてきた太陽光発電の実験から、この地での発電の有効性と可能性を実証する。ゴビ砂漠の太陽を未来のアジアのエネルギー源に！

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Abstract This paper presents the evaluation results of a long-term performance of PV modules from actual data measured over a period of more than 10 years in the Gobi Desert of Mongolia. For the purpose of estimating solar energy potentials and durability of PV systems in the Gobi desert area, a data acquisition system, which includes crystalline silicon (c-Si), polycrystalline silicon (p-Si) modules and precision pyranometer, thermometer and anemometer, was installed at Sainshand city in October, 2002. This system has been measuring 23 parameters including solar irradiation and meteorological parameters in every 10 minutes. It has been observed that the high output gain due to the operating condition in an extreme low ambient temperature and the PV module degradation rate indicated over -1.3 [%/yr] after 10 years exposure test.

Keywords Solar technology; Solar energy resources; Gobi desert; Mongolia

1. Introduction

The Gobi Desert, Mongolia, is one of the most promising candidate sites for introduction of the 100MW class Very Large Scale Photovoltaic Systems (VLS-PV) specified by Task 8 "Very Large Scale Photovoltaic Power Generation Systems" conducted as part of the IEA Photovoltaic Power Systems Program (IEA PVPS).[1)] Within the framework of the IEA PVPS Task 8 activity, a conceptual design has been developed and a trial calculation of the costs associated with power generation and construction of a VLS-PV system in the Gobi Desert area has been performed.[2)]

The meteorological environmental characteristics of the Gobi Desert may affect the PV system performance and design specifications. Therefore, it is necessary to clarify the factors that will affect the system design, operation, and maintenance. However, no useful reference data are available and there have been no case studies analyzing solar energy resources or performance for PV system installation in the Gobi Desert area.

In the Gobi Desert, Mongolia, we set up two types of photovoltaic modules and checking devices (e.g., I-V curve tracer, etc.) as well as meteorological devices to study the characteristics of photovoltaic system operation under such severe environmental conditions. The present study was carried out to verify the output simulation technique for the VLS-PV to confirm the efficiency of using a large-scale concentrated photovoltaic system in this area, and to clarify the specific requirements for system design.

To clarify the actual environmental capabilities (loss analysis) in the Gobi Desert, we measured meteorological data, such as the amount of solar irradiation and temperature, and the I-V characteristics of the photovoltaic modules.

2. Experimental Setup

In order to determine the potential of VLS-PV in Gobi desert area, two types of the crystalline silicon PV modules and checking devices (e.g. I-V curve tracer, etc.) have been installed as well as a new data acquisition system in Sainshand (44°54' N and 110°07'E) - the field site (see Fig.1, 2), which is located in the southeastern part of Mongolia. The data acquisition system (see Fig.2) is automatically switched on every 10 min and records the total solar irradiation received on the horizontal and 45-degree tilted surfaces, site meteorological data and measures PV module current-voltage (I-V) curves.

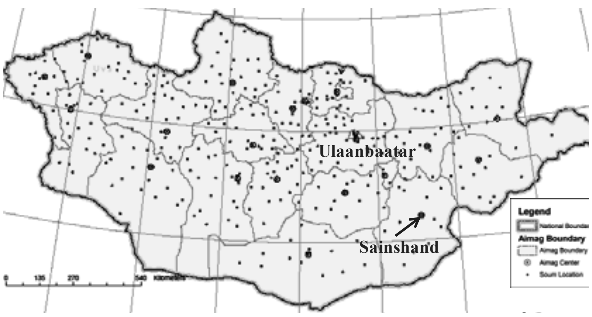

Fig. 1 Location of the exposure test site

Fig. 2 Overview of the experimental set-up

Measurement items listed below line:
1. Global Irradiance in horizon
2. In-plane Irradiance, at 45 degrees
3. Wind Speed & Direction
4. Air Temperature
5. Humidity
6. Albedo
7. Short-circuit current I_{sc}
8. Open-circuit voltage V_{oc}
9. Current at maximum power I_{pm}
10. Voltage at maximum power V_{pm}
11. Temperature of modules T_1,T_2

Table 1 Electric characteristics of PV modules on the STC

PV module name and Type		PV module-1	PV module-2
Parameters	Unit	p-Si	c-Si
Short-circuit current (I_{sc})	A	5.3	4.8
Open-circuit voltage (V_{oc})	V	21.3	21.7
Current at max. power (I_{pm})	A	4.7	4.4
Voltage at max. power (V_{pm})	V	17.1	17.0
Maximum power rating (P_{max})	W	80	75
Temperature coefficient	W/°C	0.373	0.321

3. Analysis Method

The field data analysis is divided into 3 parts regarding environmental conditions, solar energy resource evaluation, and photovoltaic (PV) performance. The environmental condition indices include ambient and module temperatures, average wind speed, humidity, and albedo. For evaluation of the solar energy resource, we use sunshine duration time, monthly average irradiation, and irradiation variable ratio. The PV Module performance indices include reference yield, array (module) yield, and performance ratio.[3)]

In this analysis, we used 10 years of data collected from March 2003 to December 2012. First, raw data obtained from the test site was checked and correctable noise was filtered.

1) Environmental condition indices
The average values of the ambient temperature, module backside temperature, wind speed/direction, humidity and albedo will be indicated to determine the real environmental situations of PV modules. We will compare measured meteorological data to an average year data of local weather station, in order to evaluate the environmental conditions during the measurement period to a normal year.

2) Solar energy resource indices
The horizontal and in-plane irradiation [kWh/m^2/day], the time of sunshine duration $T_{Meas.Duration}$ [hour/month] and fraction F_{SD} to possible sunshine duration time were used for the indices of solar energy resource. In this case, possible sunshine duration time is the mean for a clear day's duration time. We will compare monthly irradiance and sunshine duration time with local weather station data, in order to evaluate the irradiance during the measurement period.

$F_{SD}=T_{Meas.Duration}/T_{Possible\ Duration}$ (1)

3) PV module performance indices
All system performance data have been evaluated in terms of operational performance and reliability. The evaluation procedures are based on the IEC Standard 61724 [7].

$Y_r = H_A / G_S$ (2) $Y_A = E_{A,d} / P_{max}$ (3)
$PR = Y_A / Y_r$ (4)

The *reference yield* Y_r is based on the in-plane irradiation H_A and represents the theoretically available energy G_S per day and kW_p. The *array yield* Y_A is the daily array energy output $E_{A,d}$ per kW and represents the number of hours per day that the array would need to operate at its rated output power P_{max} to contribute the same daily array energy to the system as it was monitored. The *array performance ratio PR* is the ratio of actual array output energy to the energy theoretically available (i.e. Y_A/ Y_r). It is independent of location and array size and indicates the overall losses on the array's rated output due to module temperature and incomplete utilization of irradiation. Array is mean test module in our case.

4. Results

Environmental condition: The PV module, frame, and cable were working over a wide range of temperatures and were subjected to severe thermal stress. The monthly ambient temperature (average, minimum, maximum) value ranged from –30°C to +40°C (see Fig.4). The monthly average wind speed (6 years) indicated 3.0 [m/s] at a height of 3 m, and wind in spring was strong (over 4 [m/s]) than other season (see Fig.5).

The daily transition of ambient and module temperature is shown in Fig. 3 by the monthly average hour values. The difference between daytime and nighttime air temperature was around 10°C. The rise in module temperature was from 15 to 20°C relative to ambient temperature, and module temperature was kept below the standard conditions of 25°C in April and January.

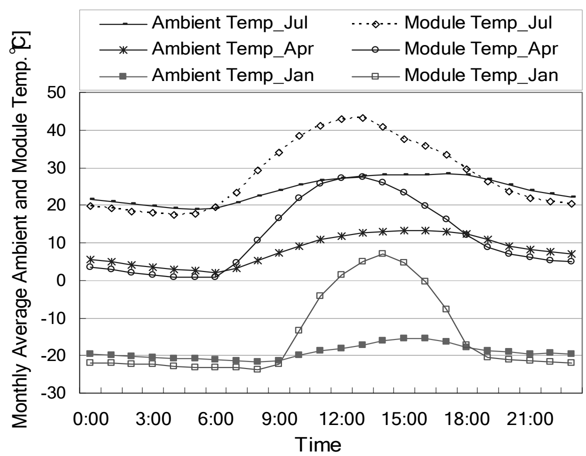

Fig. 3 Daily transition of ambient and module temperatures by monthly average value

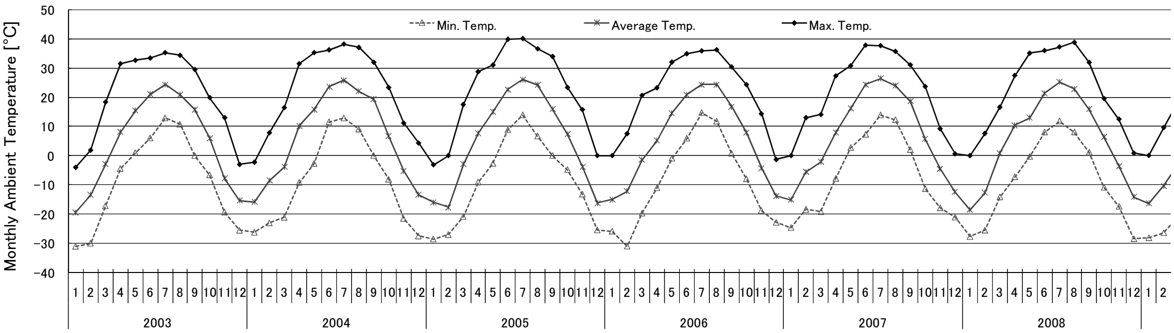

Fig. 4 Monthly Ambient Temperatures (Average, Min, Max) [°C]

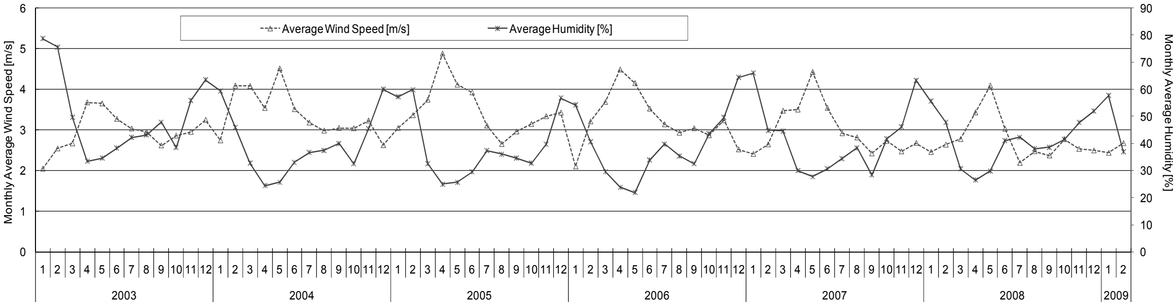

Fig. 5 Monthly Average Wind Speed and Humidity

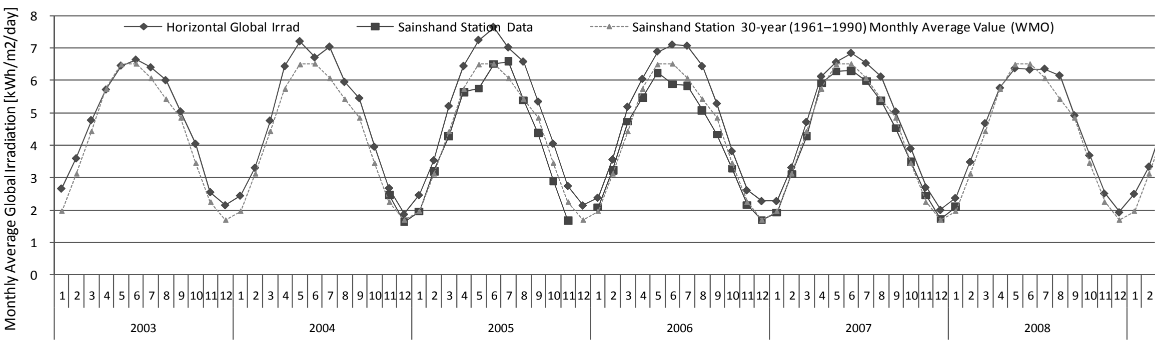

Fig. 6 Monthly Average Horizontal Global Irradiation [kWh/m^2/day]

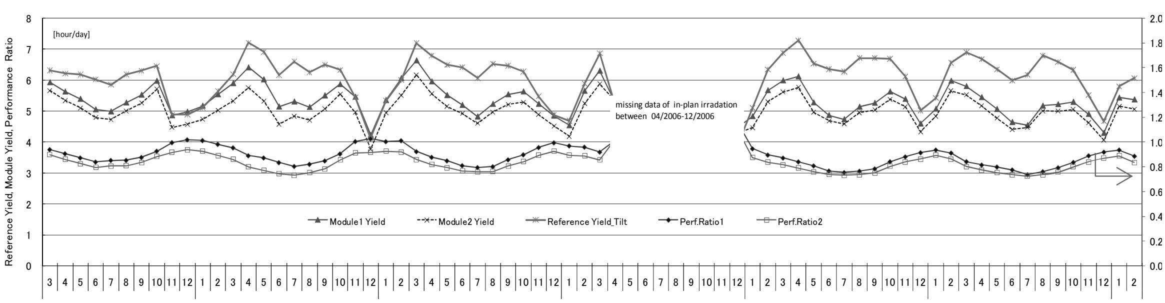

Fig. 7 Reference Yield Yr, Array Yield YA, Performance Ratio by monthly average value

Solar Energy Resource: Figure 6 shows the monthly average values of horizontal global irradiation with comparison of normal year (1961–1990, 30-year statistic values of Sainshand Weather Station by the WMO). Solar irradiations of 2003, 2007, and 2008 were similar to those in a normal year. The mean of horizontal irradiation was 4.77 [kWh/m^2/day], which was 1.5-fold greater than that in Sapporo, Japan. The annual average of in-plane irradiation was 5.95 [kW/m^2/day] (6 year average). The tilted irradiation data showed relatively small variation within a year, as precipitation is concentrated in the summer.

PV Module performance: Figure 8 shows the annual PV module yields. The mean of 6 year annual PV module yields were Y_{A1}=1932 and Y_{A2}=1822 [h/yr], indicating that each module worked for 1932 h and 1822 h by rated power, P_{max}, in the year.

It has been observed that the high output gain (see Fig.7) due to the operating condition in an extreme low ambient temperature. Strong seasonal variations were apparent in the performance of both modules. The PR of module 1 showed very high values of >1.0 in winter and around 0.85 in the warm season due to the effect of module temperature. The PV module degradation rate indicated −1.3 [%/yr],−0.96 [%/yr] after 10 years exposure test.

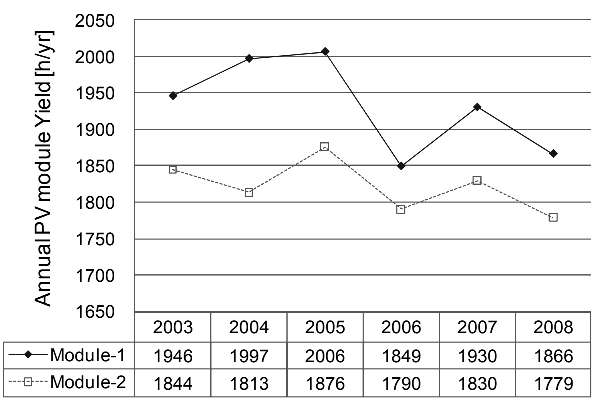

Fig. 8 Annual PV Module Yield [h/yr]

Table 2 Degradation ratio of PV modules (chosen data measured near STC)

Year	PV-1 poly-c-Si	Degrade Rate	PV-2 mono-c-Si	Degrade Rate
2003	0.997	0.345	0.991	0.901
2004	1.005	-0.245	0.974	1.29
2005	0.992	0.257	0.99	0.333
2006	1.006	-0.143	1.016	-0.396
2007	0.928	1.442	0.94	1.201
2008	0.906	1.563	0.916	1.398
2009	0.907	1.329	0.911	1.273
2010	0.909	1.137	0.909	1.137
2011	0.915	0.939	0.933	0.747
2012	0.869	1.31%	0.904	0.96%

5. Conclusions

In this paper, outdoor performance tests of two types of PV modules were conducted in Sainshand City, Mongolia. The results described here indicated high output gain due to the extremely low ambient temperature and the module performance ratio showed high values in winter. In summary, the results of the present study show that PV modules with high temperature coefficients, such as crystalline silicon, are advantageous for use in the Gobi Desert area.

References

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2) K. Kurokawa, editor: Energy from the Desert, Feasibility of Very Large Scale Photovoltaic Power Generation (VLS-PV) Systems, James & James Ltd: UK, May, 2003, 195 pages

3) Amarbayar Adiyabat, Kenji Otani, et al., Evaluation of Solar Energy Potential and PV module Performance in the Gobi Desert of Mongolia, Progress in Photovoltaics, May 2006, pp.553–566, DOI: 10.1002/pip.692