A COST ANALYSIS OF VERY LARGE SCALE PV (VLS-PV) SYSTEM ON THE WORLD DESERTS

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ABSTRACT

To preserve the Earth, a 100MW very large-scale photovoltaic power generation (VLS-PV) system is estimated assuming that it is installed on the would deserts, which are Sahara, Negev, Thar, Sonora, Great Sandy and Gobi desert. These deserts are good for installing the system because of its big irradiation and large land area. PV array is dimensioned in detail in terms of array layout, support, foundation, wiring and so on. Then generation cost of the system is estimated based on the methodology of Life-Cycle Cost (LCC). As a result of the estimation, the generation cost is calculated as 5.3 cent/kWh on Sahara desert, 6.4 cent/kWh on Gobi desert assuming PV module price of $1.0/W, system lifetime of 30 years and interest rate of 3%. These results suggest that VLS-PV systems are economically feasible on sufficient irradiation site even if existing PV system technologies are applied, when PV module price will decrease to a level of $1.0/W.

INTRODUCTION

In these years, the world economic growth and population increase need more energy, especially in developing countries. If world energy demands continue to increase, the primary energy source will be exhausted in the this century. In addition, this issue causes a varitety of serious environmental issues such as the global warming, acid rain and so on. Renewable energies are expected to resolve both the energy and the environmental issues and solar energy is one of promising renewables. Although the solar energy is of low density by nature, it has a large potential assuming that world deserts can be utilized. Therefore the authors have been investigating a very large-scale photovoltaic power generation (VLS-PV) system on desert. Even the Gobi desert that locates on high latitude has higher irradiation (4.7kWh/m^2/d) than Tokyo (3.5kWh/m^2/d). Fuerthermore, Sahara desert has more irradiation as 7.4kWh/m^2/d. Theoretically, PV systems installed on the Gobi desert with 50% space factor, has potential to generate energy as much as the recent world energy supply (361EJ in 1997).

The purpose of this study is to design the VLS-PV System on major world deserts which are shown in Fig.1 and to investigate its feasibility from an economic viewpoint.

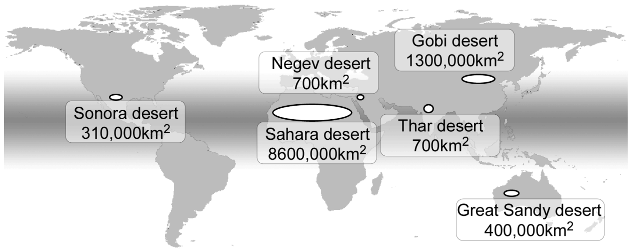


Fig.1 Selected world deserts location and extent

METHODOLOGY OF EVALUATION

To evaluate the potential of VLS-PV system in detail, generation cost of VLS-PV system was estimated in consideration of a methodology of “Life-Cycle Cost (LCC)”, that is, manufacture and transportation of system components, system construction, and operation.

MAJOR ASSUMPTIONS

It is considered in this study that a 100MW VLS-PV system is installed on the world deserts. The VLS-PV system is designed based on the following assumptions.

(1) Both Irradiation and ambient temperature data referred from World Irradiation Data Book[1] used for system designs, as shown in Table 1. If it has no

in-plain irradiation data on the installation sites, it is estimated by using methods which are distribution of direct, diffuse and total solar radiation, and estimation for tilted surface.

(2) The VLS-PV system is to be installed in a gravel desert which consists of small rocks. Sand problem is seems to be small.

(3) Total capacity is about 100MW, which consists of four sets of 25MW unit field. A 25MW unit consists of 50 sets of 500kW unit system. A 500kW unit system has 4200 PV modules. The total PV modules in 100MW system results in 840000 pieces.

(4) South-faced fixed flat array structure and foundation are designed. Wind pressure and earthquake are also taken into account.

(5) Polycrystalline silicon PV module with 12.8% efficiency is employed.

(6) System performance ratio is assumed considering operating temperature, degradation, load matching factor, efficiency factor, inverter officiating and so on, as shown in Table 1.

(7) The system lifetime assumed to be 30 years.

(8) Module and inverter price, and array tilt angle are given as valuable parameters. The four levels of module price are assumed as 1, 2, 3, 4 US$/W. Inverter unit price of 500kW is also set to 0.15, 0.17, 0.20, 0.22 million US$ for each module price. Interest rate is 3% (typical), 2% (supposing soft loan), and 6% (from ordinary financial institution). This paper show the results based on 3% interest rate.

(9) Array support and foundation are produced in the country where the VLS-PV system is installed, and other system components such as modules, cables and inverters are manufactured in Japan, USA or Australia. All the components are transported to the installation site by marine and land transport. Land preparation is also considered.

(10) The method of operation and maintenance are calculated in view of experience of real PV system model, PV-USA project[2].

(11) Three shifts of three operator team work in 100MW PV station. One team works in maintenance, and the other teams operate for alternation.

(12) Concerning labor cost, different labor requirement for system construction was estimated by considering local conditions of each country, and unit labor cost was referred from ILO statistics etc. Furthermore a supervisory charge is added to the cost for the installation of certain apparatus.

(13) Decommission stage is not included in this study stage now.

DESIGN PROCEDURE OF VLS-PV SYSTEM

Based on the assumptions described above, the VLS-PV system on the Gobi desert is designed in detail. Designing procedures divided into several steps; PV module layout, array support design, foundation design, and wiring. According to the design standard on structures for transmissions[3], rectangular foundation is designed.

The shorter and simple wiring is designed in order to prevent miss wiring. The current capacity of cable is selected to make voltage drop less than 4%. It is determined from Japan Industrial Standards-JIS. These design schemes are shown in Fig.2.

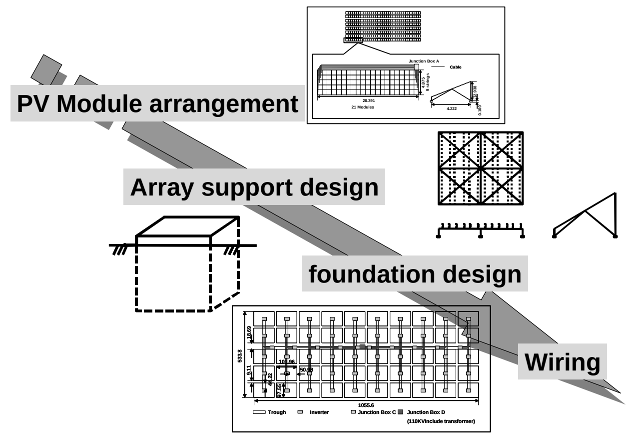


Fig.2 Image of design procedure

Table 1 Basic data for the deserts used in this study

		Unit	Sahara (Mauritania)	Negev (Middle-east)	Thar (India)	Sonora (Mexico)	Great Sandy (Australia)	Gobi (China)
System performance ratio			0.69	0.73	0.73	0.70	0.70	0.78
Annual average ambient temperature		ºC	30.2	18.9	26.9	18.4	26.1	5.8
Land area		$10^3 km^2$	8600	7	200	310	400	1300
Annual average global irradiation		$kWh/m^2/yr.$	2685	1945	2172	1737	2343	1701
Annual in-plane irradiation	[10º]	$kWh/m^2/yr.$	2756	2062	2106	2314	2431	1854
	[20º]	$kWh/m^2/yr.$	**2774**	2128	2175	2394	**2464**	1964
	[30º]	$kWh/m^2/yr.$	2716	**2139**	**2190**	**2420**	2435	2026
	[40º]	$kWh/m^2/yr.$	2556	2099	2143	2387	2347	**2037**
Unit labor cost for construction		US$/yr.	1102	15227	403	2187	30747	595

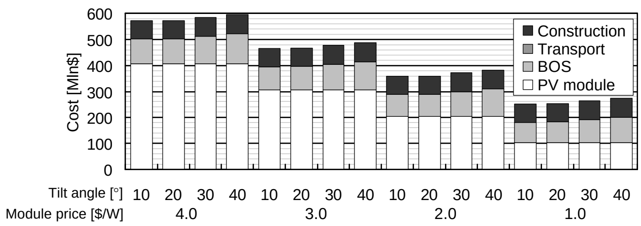
EVALUATION RESULTS

System Design

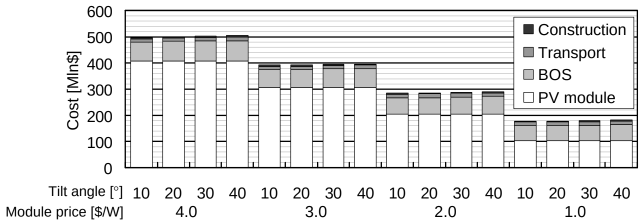
The 100MW VLS-PV system on the world desert was designed on the basis of the above assumptions. This system required 1.3 km^2 to 2.6 km^2 land area. The amount of array support and foundation increase in proportion to the tilt angle because of assumed wind pressure (42 m/s). Array support requirement ranged from 9 thousand to 11 thousand ton steel, and foundation needed 90 thousand to 200 thousand ton concrete. Land requirement also increased in proportion to the tilt angles due to spacing between PV arrays. The increase in land requirement resulted in the increase in cable length.

Cost Estimation

In this study, both total investment cost and O&M cost of 100MW PV system for each installation site were estimated to obtain generation cost of the PV system.



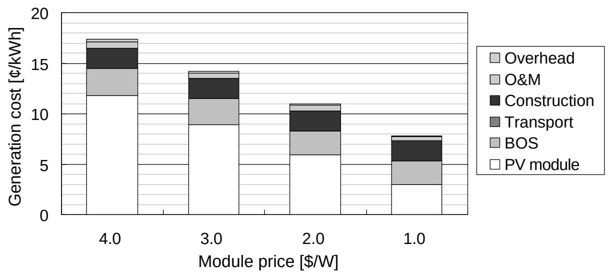
(a) Great Sandy



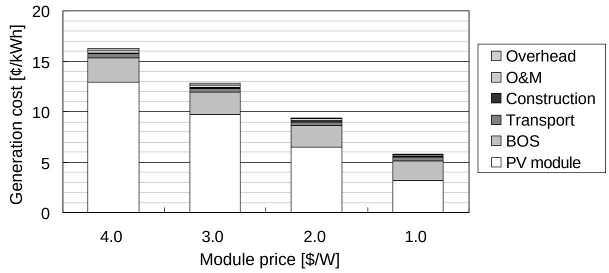
(b) Gobi

Fig.3 Total investment cost of system construction

Total investment cost includes labor cost for system construction as well as system component cost. Fig.3 represents example of the investment cost on Great Sandy and Gobi desert for deferent PV module prices and deferent array tilt angles by each cost component. Even though $1.0/W PV module is assumed, it is first majority of the total investment cost. It is the most expensive at 40º array tilt angle and the least at 10º array tilt angle, since requirement of array support, foundation and labor for system construction increases as array support is inclined. The specious reasons of deference in cost between deserts are power generation and labor cost. A majority of construction cost was labor cost, which had big difference between countries as shown in Table 1. For example about one third of the total investment cost was construction even at $1.0/W on Great Sandy. On the other hand, the least investment cost was estimated at both Sahara and Gobi mainly due to low labor cost. It was no more than 2% of the total at $1.0/W.



(a) Great Sandy



(b) Gobi

Fig.4 Break down of generation cost for optimal tilt angle

Table 2 Annual power generation and Generation cost

	Array tilt angle	Unit	Sahara (Mauritania)	Negev (Middle-east)	Thar (India)	Sonora (Mexico)	Great Sandy (Australia)	Gobi (China)
Annual power generation	[10º]	GWh/yr.	193	153	157	165	174	147
	[20º]	GWh/yr.	**194**	158	162	171	**176**	156
	[30º]	GWh/yr.	190	**159**	**163**	**172**	174	161
	[40º]	GWh/yr.	179	156	160	170	168	**162**
Generation cost	[10º]	Cent/kWh	5.3	7.4	6.8	6.8	8.3	6.9
($1.0/W module price)	[20º]	Cent/kWh	**5.3**	**7.2**	**6.6**	**6.6**	**8.3**	6.5
	[30º]	Cent/kWh	5.5	7.3	6.8	6.8	8.7	**6.4**
	[40º]	Cent/kWh	6.0	7.5	7.3	7.3	9.4	6.4

The generation cost of the 100MW VLS-PV system for different tilt angles and different PV module prices are assumed 30 years lifetime and 3% of annual interest rate on the world deserts. Annual power generation and generation cost are given in Table 2 and Fig.4. Optimal array tilt angle depended on both annual cost and annual power generation. The most annual power generation was the case of Sahara because of its most irradiation. The least generation cost of the Gobi case was obtained at 30º-tilt angle because of its high latitude. And other systems installed on middle latitude deserts such as Sahara, Negev, Thar, Sonora and Great sandy gave the lowest generation cost at 20º array tilt angle, which were different from that for the most annual power generation. On the Gobi desert, though the generation cost with $4.0/W module price corresponded to 18 cent/kWh, it was reduced to about 6.4 cent/kWh with $1.0/W module price.

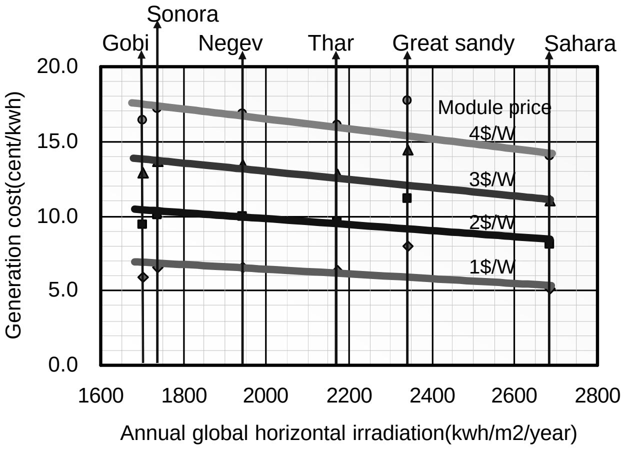


Fig.5 Generation cost as function of annual irradiation

CONCLUSION

A 100MW VLS-PV system installed on the six deserts in the world was designed and its potential was evaluated from an economic viewpoint. Assuming $1.0/W of PV module price and 3% of annual interest rate, generation cost of the VLS-PV system was estimated 5.3 ¢/kWh on Sahara desert.

Fig.5 that is a summary of generation cost of VLS-PV on the deserts suggests that the VLS-PV system is economically feasible for all the sites if the module price reduces to $1.0/W. In addition, these large-scale projects make a lot of employments. One of case study needs 1500 labors in every year to construct it. This employment may look forward economic development in the area. This important factor should be included in this study.

To realize the VLS-PV system, however, other aspects such as environment issues, socio-economic issues and sustainability as well as economic issues should be considered. Additionally, remote sensing is a contributory method to know fit point for it.

The authors have a plan to design and evaluate the VLS-PV system installed on deserts with other advanced technologies such as CdS, amorphous, and concentrating, tracking system by applying the same approach used in this study. In addition, the VLS-PV may be useful for sustainable greening since generated electricity can be used for irrigation. Our study does not include a decommission stage at this moment, but it is also essential components. It will be included in the near future.

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