COMPARATIVE STUDY OF FIXED AND TRACKING SYSTEM OF VERY LARGE-SCALE PV (VLS-PV) SYSTEMS IN THE WORLD DESERTS

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ABSTRACT: A desert has big potential, such as high irradiation and huge land area. And desert area is not only sand desert, but many types of lands exist. For example, rock desert, desert step, mountains and gravel desert, which is consist of small rocks and hard soil. Authors are focused on its potentials and simulate a 100 MW Very Large-Scale PV system installed in a desert area to obtain a possibility. For the simulation, Life Cycle Analysis is applied and it is estimated very carefully. In this study, fixed flat plate system and sun tracking system with flat plate PV module are evaluated. As a result, generation cost of 6-10 U.S.cent/kWh for Sun tracking system and 8-12 U.S.cent/kWh for static system with 2 USD/W PV module are obtained in world desert cases. It is obtained that possibility of installing the Very Large-Scale Photovoltaic power generation system is high.
Keywords: PV system, Tracking, Economic Analysis

1 INTRODUCTION

A Very Large-Scale Photovoltaic (VLS-PV) Power Generation System is interesting option for resolving energy and environmental problems. Figure 1 shows energy outlook toward 2050 and is presented by OECD/IEA [1]. It says that total primary energy in 2050 is 2.5 times the supplies in 2000. International Institute for Applied Systems Analysis: IIASA developed energy and CO2 emissions' scenarios for Intergovernmental Panel on Climate Change: IPCC. By their calculations, total CO2 emissions reach 2.5 times bigger than 2000 at A1B scenario which is rapid technological change for non-fossil-fuel technologies, and 2 times bigger than 2000 at A1T scenario which is also rapid technological change for both fossil and non-fossil-fuel technologies.

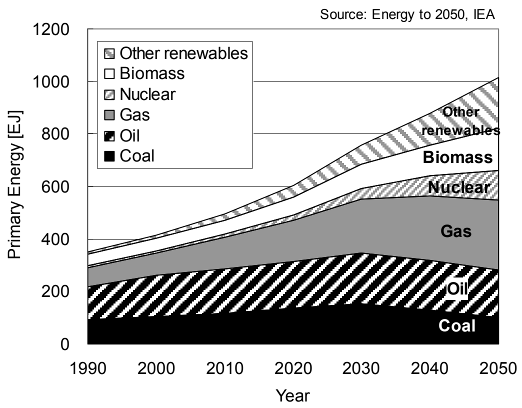

Figure 1: Total primary energy supply by fuel [1]

Photovoltaic power generation system is one of promising renewable energy, because it requires no fuel, no emission and very low maintenance at the operation stage. However, the solar energy from sun light has a disadvantage, that is, its low energy density by nature. Therefore, to generate large power such as nuclear power plant, the PV system must be introduced at very large-scale. High irradiation and very large unutilized land areas exist in world deserts. For example, even the Gobi desert that locates on high latitude has higher irradiation (4.7kWh/m2/d) than Tokyo (3.5kWh/m2/d). Furthermore, the Sahara desert has more irradiation, or 7.4kWh/m2/d. Theoretically, PV systems installed in the Gobi desert with 50% space factor, has potential to generate energy as much as the recent world energy supply.

2 OBJECTIVE

A solar tracking PV system is good option for increasing energy production. And the irradiation potential is easy to know by calculation [2], and some demonstrations reported good result [3].

The authors have researched static VLS-PV systems in the world desert and tracking VLS-PV system, which is single, horizontal, North-South-oriented axis tracking structures with flat-plate module, in Gobi desert [4]. It was reported that tracking system have a potential of cost, energy and CO2 reduction. The tracking system is known that irradiation in low latitude is higher than high latitude. In this paper, the tracking VLS-PV systems installed in not only Gobi desert but also world deserts evaluated from economic view point by LCA method to obtain its potential in low latitude arid land area.

3 METHODOLOGY

3.1 Basic methodology

A methodology of "Life-Cycle Assessment (LCA)" is a appropriate measure to evaluate the potential of VLS-PV systems in detail, because a purpose of this methodology is to evaluate its input and output from cradle to grave. In this study, generation cost of the VLS-PV system was calculated with the method. These index is defined by following equation.

$$\text{Generation Cost [cent/kWh]} = \frac{\text{Annual expense of the PV system [cent/year]}}{\text{Annual power generation [kWh/year]}}$$

3.2 Design scheme

Based on concept of LCA, VLS-PV system followed these steps. Detailed schemes are shown in Chapter 4.

1) Basic assumptions such as capacity, component, transport etc. are planed.
2) Irradiations for static and tracking system in world deserts are calculated.
3) Module layout, array structures, foundations, transmissions and wires are designed.
4) All materials' price, maintenance, tax, wages etc. are considered, and generation costs are calculated.

4 SYSTEM DESIGN

Six deserts which are Sahara, Negev, Thar, Sonoran, Great Sandy and Gobi are elected for installing VLS-PV system. Two deferent places in Sahara desert were assumed, because the size is very large. A desert area is suitable for PV system in view of irradiation and land area. Especislly gravel desert should be elected for installing the system. Because it consists of small rocks, and it is more flat and firm than sand or rock desert. Sand problems such as sand storm are seemed to be small in this area.

4.1 Basic assumptions

These assumptions are applied for both Fixed and Tracking system. (1)The fixed and tracking VLS-PV system is assumed to be 100 MW. (2)Fixed flat plate system is faced south. Tracking system is Single, horizontal, North-South oriented axis tracking with flat plate modules. (3)A PV module is assumed KC120S produced by Kyocera [5] (see Table 1). (4)Life-time is 30 years. (5)500 kW dc-ac inverters are installed, and 6 kV/110 kV transformers pressurize voltage. (6)Basic unit is 250 kW, 25 MW unit is consisted from 50 500 kW unit. Four 25 MW unit make 100 MW VLS-PV. (7)In case of Great Sandy desert, all items are produced in its country. In Sonoran desert case, PV module, cable and common apparatuses are produced in USA and transport by truck. In developing countries' case, PV module, cable and common apparatuses are imported from near developed country. Array structures, foundations, troughs and transmission towers are produced by their country. In this study, only marine transport is considered. (8)Land preparation is considered.

Table 1: Specification of a module used in this study [5]

Module	Kyocera KC120S (Poly-Si)
Nominal power	120 W
Efficiency of module	12.8 %
Open circuit voltage	21.4 V
Short circuit current	7.45 A
Height, Width	0.971 m × 0.966 m
Weight	11.9 kg
Coefficient of power [6]	-0.50 %/°C

4.2 Irradiations

Both irradiation and ambient temperature data were referred from World Irradiation Data Book[7] used for system designs, as shown in Table 2. If the installation sites have no direct and diffuse irradiation data, which are estimated from grovel irradiation data by using Iqubal model [8]. In case of no duration of sunlight data, Liu-Jordan model [9] is applyed (see Table 3). In-plain irradiation data is calculated by using rb model, Hey model [10] and isotropic model [11]. Irradiation of tracking system is obtained to calculate a method which is referred to JSES [11], and is changed a part of above method.

Table 2: Dividing beam and difuse irradiation model

	H Gh	H Dh	DS	Model
Sahara (Nema)	O	×	O	Iqubal
Sahara (Ouarzazate)	O	×	O	Iqubal
Negev	O	×	O	Iqubal
Thar	O	O	O	–
Sonoran	O	×	O	Iqubal
Great Sandy	O	×	×	Liu-Johdan
Gobi	O	O	O	–

H Gh: Global horizontal irradiation
G Dh: Global diffuse irradiation, DS: Duration of sunlight

4.3 Module layout

PV arrays are with enough space between them. It was assumed that PV array don't shade others when 10° solar elevation in midwinter. Considering open circuit voltage and layout, 18 modules per one string for tracking system, and 21 modules per one string for static system (See Figure 2).Basic arraies were placed as shown in Figure 3. It is considered for simple wiring and enough spacing.

4.4 Array structures and foundations design

Array structure and foundations were designed based on 42 m/s wind velocity and 0.2 G earthquake. A zinc-plated stainless steel (SS 400) for array and concrete for foundation were designed by using Design standard of structure steel [12].

4.5 Transmissions

Electric transmissions aree assumed 100 km, 2 channels and 110 kV for connecting to existing transmission. It consists of steel towers, foundations,

Table 3: Geographic information for world deserts

Desert		*Sahara*	*Sahara*	*Negev*	*Thar*	*Sonoran*	*Great Sandy*	*Gobi*
Location		Nema 16°N 7°W	Ouarzazate 31°N 6°W	Bet dagan 32°N 34°E	Jodhpur 26°N 73°E	Chihuahuan 28°N 106°W	Port headland 20°S 118°E	Hoh hot 40°N 111°E
Performance ratio		0.69	0.73	0.73	0.70	0.73	0.70	0.78
Ambient temperature		30.2 [°C]	19.2	18.9	26.9	18.4	26.1	5.8
In-plane irradiation	Grobal	2688	2042	1943	2173	1998	2345	1702
	Tilt angle=10°	2750	2159	2042	2301	2100	2418	1848
	Tilt angle=20°	2769	2235	2104	2381	2170	2451	1958
	Tilt angle=30°	2721	2254	2115	2407	2184	2422	2020
	Tilt angle=40°	2604	2221	2075	2374	2148	2334	2031
Irradiation on one axis tracker		3,711	2,885	2,754	3,010	2,747	3,327	2,411

[$kWh \cdot m^{-2} \cdot yr^{-1}$]

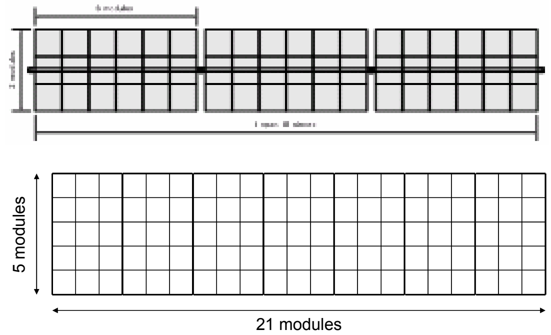

Figure 2: Module layout for tracking (upper) and static (lower)

cables and grand wires. Cables and ground wires are decided TACSR 410 sq and AC 70 sq, 22.0 ton steel towers and 22.1 m^3 foundations are required 334 towers with foundations for 100 km transmission.

4.6 Operation and maintenance

The method of operation and maintenance are calculated in view of experience of real PV system model, PV-USA project [13]. Three shifts of three operator team work in 100MW PV station. One team works in maintenance, and the other teams operate for alternation. 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 [14] etc. Furthermore a supervisory charge is added to the cost for the installation of certain apparatus. Decommission stage is not included in this study stage now.

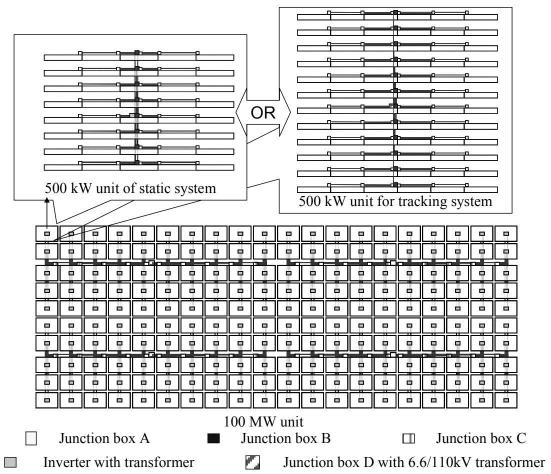

Figure 3: Array layout for 100 MW VLS-PV system for static and tracking.

5 EVALUATION RESULT

Some parameters are assumed before evaluation. System performance ratio was assumed considering operating temperature, degradation, load matching factor, efficiency factor, inverter officiating and so on, as shown in Table 2. 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$/W. Inverter unit price of 500kW is also set to 0.136, 0.159, 0.181, 0.204 million US$ 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.

Based on these assumptions and designs, 100 MW static and tracking VLS-PV systems were evaluated. Table 5 shows required materials for static and tracking system in Sahara desert. Tracking system in Sahara desert required 4.4 km^2 land area which is twice as fixed flat plate system. Array support requirement ranged 10-11 thousand ton steel, and foundations are required 46 thousand m^3 concrete.

In this study, both investment cost and O&M cost of 100MW PV system for each installation site were estimated to obtain generation cost of the PV system. Total investment cost includes labor cost for system construction as well as system component cost. But worm gear price is not considered. Figure 4 represents example of the annual cost in Gobi desert for deferent PV systems by each cost component. They are normarized capacity of 100 MW for comparison. A BOS and property tax have defferences between them because of tracking mechanizm, and tracking system is higher annual cost than static system. However, annual power

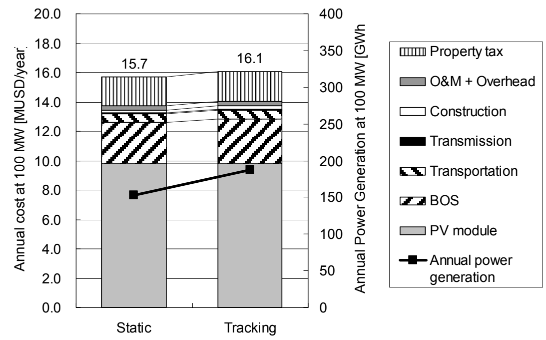

Figure 4: Breakdown of annual cost and annual power generation which are normarize as 100 MW.
(Static: 30°, Gobi desert case)

Table 4: Estimation result of Generation cost for Fixed flat plate and Tracking VLS-PV system

Desert	*Sahara*		*Sahara*		*Negev*		*Thar*		*Sonoran*		*Great Sandy*		*Gobi*	
Location	Nema		Ouarzazate		Bet dagan		Jodhpur		Chihuahuan		Port headland		Hoh hot	
Optimum tilt angle*	20°		20°		20°		20°		20°		20°		30°	
Area of statics[km^2]	1.6		1.7		1.7		1.7		1.7		1.4		2.3	
Area of tracking	4.4		4.1		4.0		4.2		4.1		4.3		3.7	
Generation Cost** Module price 1 USD/W	5.2	4.1	6.3	5.0	8.3	7.0	6.4	5.6	6.4	5.9	8.3	6.5	6.2	5.5
2 USD/W	8.4	6.6	10.2	8.0	12.3	10.1	10.0	8.5	10.2	9.0	11.8	9.1	10.0	8.8
3 USD/W	11.5	9.0	14.0	10.9	16.2	13.1	13.6	11.4	14.0	12.0	15.3	11.8	13.8	12.1
4 USD/W	14.7	11.4	17.9	13.8	20.1	16.2	17.2	14.4	17.8	15.1	18.8	14.4	17.7	15.4
Power generation [GWh/y]	194	240	166	198	156	189	170	198	162	189	175	220	160	177

*Optimum tilt angle is oprimized for generation cost.
**Unit: U.S.cent/kWh, left is generation cost of static system at optimum tilt angle, right is generation cost of tracking system.

generation is much incleasing. And the generation cost become lower as shown in Table 4.

From table 4, required area for tracking system is larger than area for static system. Because, array structure for static system have 4 poles for 1 basic array, which can hold long length, 5 modules. 1 basic array for tracking system is mede from 2 poles, whick can not keep long length array. It cause many spaces are required, and total area for tracking system become big.

generation cost of tracking system is about 20 % lower than static system, becaouse of its power generation. It is over 20 % larger than static system. However, this study is not included a land price, because desert area is assumed. If land cost is considerd, cost advantage become lower.

6 CONCLUSION

100MW Very Large-Scale Fixed plat plete and tracking power generation systems installed in World deserts were designed and its potentials were evaluated from economic viewpoint by LCA method. Figure 5 is a summary of these estimate. It show possibility of cost down by applying a tracking meckanizm. And if the module price become 2 USD/W or more less, the generation cost reaches 10 U.S.cent/kWh for static system and 8 U.S.cent/kWh for tracking system in all desert areas.

Table 5: System required materials (Sahara deset case)

Item	Unit	Static 30°	Tracking
Material requirement			
PV module	piece	848,500	785,500
Capacity	MW	101.8	94.3
Array support structure	ton	9,755	10,819
Foundation	m^3	59,578	46,061
Cable			
600 V CV 2 mm^2	km	1,434	612
600 V CV 8 mm^2 double core	km	173	219
600 V CV 60 mm^2	km	87	270
6,6 kV CV-T 22 mm^2	km	27	54
6,6 kV CV 200 mm^2	km	38	42
110 kV CV 150 mm^2	km	13	20
Trough	m^3	32,000	48,000
Tracking system	piece	–	43,600
Common apparatus			
Inverter (with transformer)	set	202	202
6,6 kV capacitor	set	202	202
6,6 KV GIS	set	4	4
110 kV/6.6kV transformer	set	5	5
110 kV GIS	set	4	4
2,4MVA capacitor	set	1	1
Common power board	set	1	1
Transportation			
Heavy oil consumption	ton	142	140
Diesel oil consumption	kl	–	–
Transmission			
Cable*			
110 kV TACSR 410 mm^2	km	1,202	1,202
AC 70 mm^2	km	100	100
Pylon (steel)*	ton	7,348	7,348
Foundation*	ton	16,977	16,977
Construction*			
Diesel oil consumption	kl	167	397
Labour requirement	Man-yr.	2,300	2,700

*Transmission is assumed 1000 MW system. One tenth data is used for calculating cost.

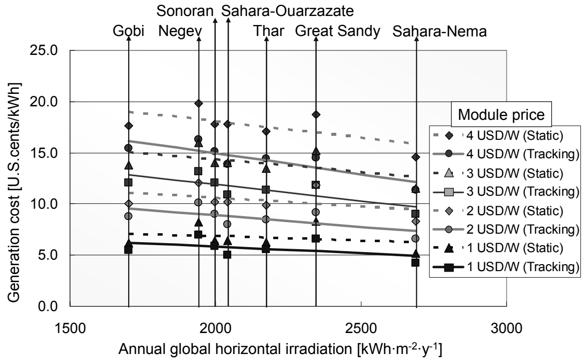

Figure 5: Best estimates of generation cost for each deserts as a function of annual global horizontal irradiation.

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