A Preliminary Study on Utilization of Desert with Agricultural Development and Photovoltaic Technology
─ Potential of Very Large-scale Photovoltaic Power Generation (VLS-PV) systems ─

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Abstract – The authors propose solution of energy problem and environmental problem. It is utilization of deserts for power plant by PV technology and agricultural development. 100 MW VLS-PV systems in the world deserts are assumed and evaluated in detail by using Life Cycle Assessment. As a result, 6 Cent/kWh cost, 2 years energy payback time, and 12 g-C/kWh CO2 emission rate are obtained in the Gobi desert case. The Very Large-Scale Photovoltaic power generation system is very promising for the energy resource saving and environmental issue.

Key words: Photovoltaic power generation system, agriculture, desert, Life cycle assessment

1. Introduction

Due to the world economic growth and population increase, world energy demand has been rapidly expanding, and food crises and reduction of species and forest are appeared. Inter national Energy Agency says, world energy demand will be twice as 2000 in 2030. United Nations says, population will be nine billion peoples as medium variant case in 2050. The authors propose a sustainable development of desert by agricultural development using Very Large-scale Photovoltaic power generation technology. This proposal solves some world issues such as energy problem, food crisis and reduction of species. To solve energy problem, utilizing desert has big possibility because it has high irradiation, and huge land area. 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 as 7.4kWh/m2/d. Anyway, agricultural development for desert is very important to resolve food crisis, desertification and reduction of forest. 87 % of desertification reasons are caused by human from United Nations' opinion. Therefore, if man-caused reasons are solved, 87 % of desertification can be stopped, and it is easy to afforest if the areas were forest in past days. In these areas in desert, people can get foreign currency, and increase employment if the areas are added agricultural technology. These things cause increase of food production in the area.

The purpose of this study is to design the sustainable community in the desert area. The community has kinds of developed technologies which are aimed at utilizing in desert. The technologies are photovoltaic power generation system, agricultural technology, and remote sensing technology. Kinds of sustainable communities with these technologies are made of afforestation, farm, Photovoltaic system and people. The authors propose high potential community, which are high possible, low energy required, low emissions and economical communities. These communities can be resolve world problems. This paper presents its possibility from photovoltaic experts.

2. Methodology of Evaluation

A methodology of "Life-Cycle Assessment (LCA)" is the best way 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, energy payback time (EPT) and CO2 emission rate of the VLS-PV system are calculated with this method. They are defined by following equations. EPT means years to recover primary energy consumption throughout its life-cycle by its own energy production. CO2 emission rate is a useful index to know how much the PV system is effective for the global warming.

$$\text{EPT[year]} = \frac{\text{Total primary energy requirement throughout its lifecycle[kWh]}}{\text{Annual power generation [kWh/year]}} \quad \text{------} (1)$$

$$\text{CO2 emission rate [g-C/kWh]} = \frac{\text{Total CO2 emission on life-cycle[g-C]}}{\text{Annual power generation [kWh/year]} \times \text{Lifetime [year]}} \quad \text{------} (2)$$

$$\text{Generation Cost [cent/kWh]} = \frac{\text{Annual expense of the PV system [cent/year]}}{\text{Annual power generation [kWh/year]}} \quad \text{------} (3)$$

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3 Installation Area: Six deserts which are Sahara, Negev, Thar, Sonoran, Great Sandy and Gobi are elected for installing VLS-PV system. A desert area is suitable for PV system in view of irradiation and land area. Gravel desert is 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. Both irradiation and ambient temperature data referred from World Irradiation Data Book[2] used for system designs, as shown in Table 1. If the installation sites have no direct and diffuse irradiation data, which are estimated from grovel irradiation data by using Liu-Jordan model. In-plain irradiation data is calculated by using rb model, Hey model and isotropic model.

4 System Assumptions: A target of this study is sustainable development with one GW VLS-PV system as shown in Fig 1. VLS-PV systems are designed based on the following assumptions.

1) This study is divided into detailed case study and economic case studies. One is a fixed flat plate PV system simulation from economic and environmental view points by using three indices in the Gobi desert. Other is a fixed flat plate PV system simulation from economic view point by cost evaluation in the world deserts which are Sahara, Negev, Thar, Sonoran, Great Sandy and .Gobi desert. Table 1 shows a list of these desert geographic information.
2) 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 modules. The total modules in 100MW system are 840,000 pieces. Layouts for Gobi desert are shown in Fig. 2.
3) South-faced fixed flat array structure and foundation are designed. Wind pressure and earthquake are also taken into account.
4) Polycrystalline silicon PV module with 12.8% efficiency is employed. It is referred to Kyocera 120S.
5) System performance ratio is assumed considering operating temperature, degradation, load matching factor, efficiency factor, inverter officiating and so on, as shown in Table 1.
6) The system lifetime assumed to be 30 years.
7) 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.
8) 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 advanced country, Japan, USA or Australia. All the components are transported to the installation site by marine and land transport. Land preparation is considered.
9) The method of operation and maintenance are

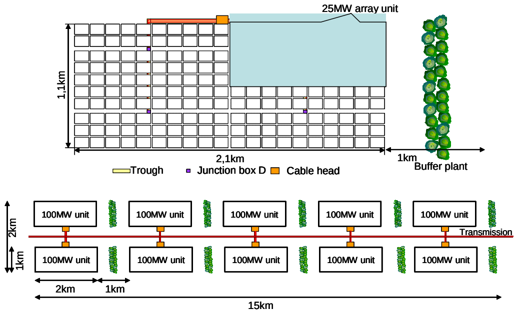

Fig. 1 Concept of 1GW PV array layout

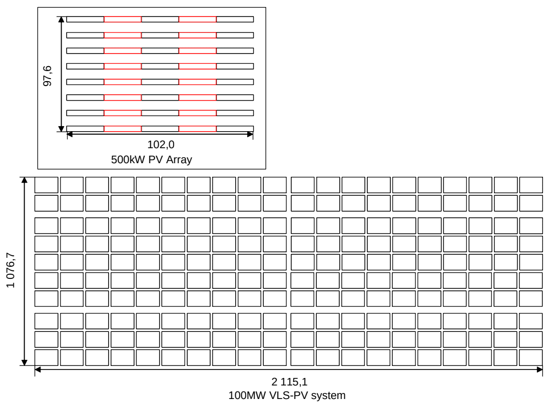

Fig. 2 Array layout for fixed flat plate system

Table 1 Geographic information for world deserts

Desert / Location		*Sahara* Nema (16°N 7°W)	*Negev* Bet dagan (32°N 34°)	*Thar* Jodhpur (26°N 73°E)	*Sonoran* Chihuahuan (28°N 106°W)	*Great Sandy* Port headland (20°S 118°E)	*Gobi* Hoh hot (40°N 111°E)
Performance ratio (PR)		0.69	0.73	0.70	0.73	0.70	0.78
Ambient temperature [°C]		30.2	18.9	26.9	18.4	26.1	5.8
In-plane irradiation	Tilt angle=10°	2,756	2,062	2,314	2,106	2,431	1,854
	Tilt angle=20°	**2,774**	2,128	2,394	2,175	**2,464**	1,964
	Tilt angle=30°	2,716	**2,139**	**2,420**	**2,190**	2,435	2,026
	Tilt angle=40°	2,559	2,099	2,387	2,143	2,347	**2,037**

calculated in view of experience of real PV system model, PV-USA project [4].

10) Concerning labor cost, different labor requirement for system construction is estimated by considering local conditions of each country, and unit labor cost is referred from ILO statistics etc. Furthermore a supervisory charge is added to the cost for the installation of certain apparatus. Three shifts of three operator team work in 100MW PV station. One team works in maintenance, and the other teams operate for alternation.

11) Decommission stage is not included in this study stage now.

5. Designing VLS-PV Systems

The authors assumed and designed the VLS-PV systems in the major deserts in detail. These case studies show characteristics of systems, and they show the best performance system configuration.

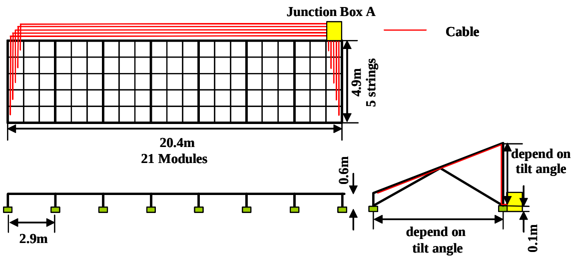

Fig. 3 Basic array structure for fixed flat plate

1. Array support structure: Fig. 3 shows the basic structure of array support. Foundation height over the ground is 0.1 m and lower height of array support is 0.2 m from the ground. It is assumed that array support is made of zinc-plated stainless steel (SS 400), and thickness of several types of steel material are chosen according to stress analysis assuming that the wind velocity is 42m/s.
2. Foundation: A cubicle foundation made of concrete is employed. Its rectangular solid is 0.8 m each considering the design standard of support structure for power transmission by the Institute of Electrical Engineering in Japan.
3. Wiring: 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.
4. Transmission: Electric transmission system is assumed 100 km, 2 channels and 110 kV. It consists of steel towers, foundations, cables and grand wires. They are considered wind velocity 42m/s. After calculations, 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.

6. Evaluation Results

6.1 Cost Estimation: In this study, both investment cost and O&M cost of 100MW PV systems 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. Even though 1.0 USD/W PV module is assumed, it is first majority of the total investment cost. A majority of construction cost is labor cost, which had big difference between countries. For example about one third of the total investment cost is construction even at 1.0 USD/W in 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 USD/W. The generation cost of 100MW VLS-PV system for different tilt angles and different PV module prices are assumed 30 years lifetime and 3% of annual interest rate in the world deserts. Annual power generation and generation cost are given in Table 2. Optimal array tilt angle depended on both annual cost and annual power generation. The most annual power generation is the case of Sahara because of its highest irradiation. The least generation cost of the Gobi case is obtained at 30º-tilt angle because of its high latitude. And other

Table 2 Annual power generation and Generation cost for 100 MW PV system

		Unit	Sahara (Mauritania)	Negev (Middle-east)	Thar (India)	Sonora (Mexico)	Great Sandy (Australia)	Gobi (China)
Annual power generation	Tilt angle= 10º	GWh/yr.	193	153	165	157	174	147
	20º	GWh/yr.	**194**	158	171	162	**176**	156
	30º	GWh/yr.	190	**159**	**172**	**163**	174	161
	40º	GWh/yr.	179	156	170	160	168	**162**
Generation cost (at optimum tilt angle)	Module price=1$/W	Cent/kWh	5.2	8.4	6.4	6.5	8.4	6.2
	2$/W	Cent/kWh	8.4	12.3	10.0	10.3	11.9	10.0
	3$/W	Cent/kWh	11.5	16.1	13.6	14.1	15.4	13.8
	4$/W	Cent/kWh	14.7	20.0	17.2	17.9	18.8	17.6

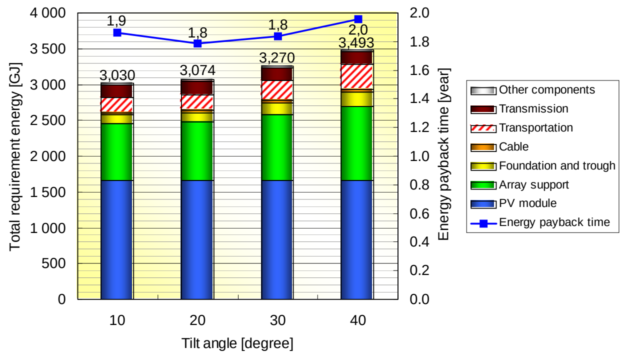

Fig.4 Total Energy Requirement and EPT

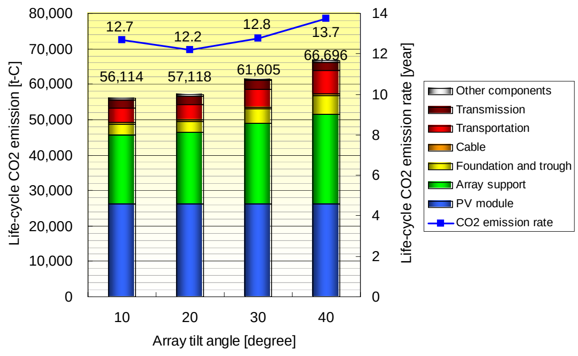

Fig. 5 Total CO2 emissions and CO2 emissions rate

systems installed on middle latitude deserts such as Sahara, Negev, Thar, Sonora and Great sandy give the lowest generation cost at 20º array tilt angle, which are different from that for the most annual power generation. In the Gobi desert case, the generation cost with 4.0 USD/W module price corresponded to 18 cent/kWh, it was reduced to about 6 cent/kWh with 1.0 USD/W module price.

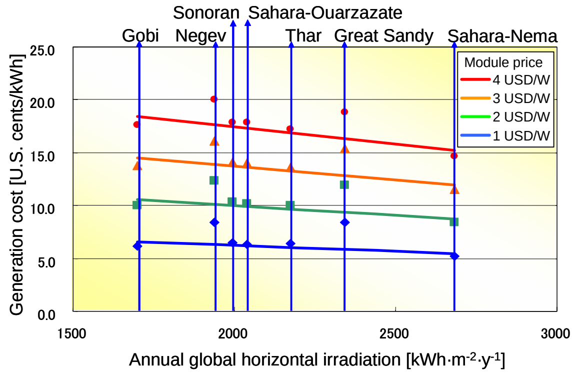

Fig. 6 Best estimates of generation cost for each deserts as a function of global horizontal irradiation

6.2 Energy and CO2 Emission Analysis in Gobi desert:

Fig.4 represents the results of total primary energy requirements and Energy Payback Time (EPT). EPT is estimated assuming electricity from the PV system would replace utility power in China where recent conversion efficiency is around 33%. Transportation also uses a certain amount of energy. Nevertheless, the EPT is still a low level. This suggests that the total energy requirement for introduction of a 100MW PV system to the Gobi desert in China can be recovered in less than two years. Fig. 5 is results of life-cycle CO2 emissions and life-cycle CO2 emission rate. Discussion of these results is the same as the total primary energy requirement and the EPT. Considering CO2 emission rate of existing coal-fired power plants, about 300 g-C/kWh, the life-cycle CO2 emission rate of a 100MW PV system is much lower.

7 CONCLUSION

A 100MW Very Large-Scale photovoltaic power generation system installed in the Gobi desert in the world desert is designed and its potential is evaluated from an economic and environmental viewpoint. Assuming 1.0 USD/W of PV module price and 3% of annual interest rate, generation cost of the VLS-PV system is estimated 6.2 cent/kWh in Gobi desert. Fig.6 that is a summary of generation cost of VLS-PV in the deserts suggests that the VLS-PV system is economically feasible for all the sites if the module price reduces to 2.0 USD/W or 1.0 USD/W. The feasibility of very large-scale photovoltaic power generation system installed in the Gobi desert in China is evaluated in depth from a life-cycle viewpoint by using three indices, i.e., life-cycle cost; energy payback time (EPT) and life-cycle CO2 emissions. This study suggests that the total energy requirement throughout the life-cycle of the PV system can be recovered in a short period much less than its lifetime. The much lower CO2 emission rate of VLS-PV than that of existing coal-fired power plants means that it is a very effective energy technology for preventing global warming.

Acknowledgment

Authors wish to thank the Sumitomo Foundation. The support makes our study more interesting.

References

[1] IEA, World Energy Outlook 2002 (2002)
[2] Japan Weather Association, World Irradiation Data Book, FY1991 NEDO Contract Report
[3] Japan Solar Energy Society, Japan Solar Energy Utilization Handbook (2000), 26pp
[4] C.Jennings, A.B.Reyes & K.P.O', Brien PVUSA utility-scale system capital and maintenance costs, WCPEC-1, Dec, 5-9, 1994, Hawaii.