Comparative Study on Potential of Very Large-Scale PV Systems (VLS-PV) in the Gobi and Sahara Desert

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ABSTRACT

A Very Large-Scale Photovoltaic power generation System (VLS-PV) has possibility to solve energy problem due to its low energy requirement in its life-cycle. Especially, arid land areas have huge irradiation and enough land area. The authors focused on these items and began to simulate its possibility with Life-Cycle Assessment method in detail. In this paper, VLS-PV systems using amorphous silicone solar cells are evaluated, because its electricity is not reduced by high temperature such as in Sahara desert. For the comparison, Sahara desert and Gobi desert case studies are evaluated.
As a result, VLS-PV system using poly crystalline silicon module is suitable for cold desert such as Gobi desert. Amorphous silicone module is comparative in high temperature area such as Sahara desert. Generation cost in Gobi desert is 13 to 15 UScent/kWh with 3 USD/W module price, and 11 to 12 UScent/kWh in Sahara desert.

1. INTRODUCTION

Authors focused on energy problem and global worming. World energy demand has been rapidly expanding due to the world economic growth and population increase, especially in developing countries. According to an IEA report, total CO_2 emissions and total primary energy supply in 2030 in the world will be twice as much as in 2000 If world energy demands continue to increase, the primary energy may dry up in this century. In addition, too much energy consumption causes a variety of serious environmental problems such as global warming, acid rain and so on. But, renewable energies are expected to resolve both the energy problem and the environmental problems. Photovoltaic power generation system (PV system) is one of promising renewables. Because the PV system need no fuel, no emission and very low maintenance at the operation stage. However, the solar energy 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/m^2/d) than Tokyo (3.5kWh/m^2/d). Furthermore, the Sahara desert has more irradiation, or 7.4kWh/m^2/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 (384 EJ in 2000). Desert area is not far from city, such as Chinese case. In this study, we assume the VLS-PV system is installed in desert area, but near city area.

2. OBJECTIVE

To obtain characteristics of amorphous silicone module as a VLS-PV system in desert areas, 100MW VLS-PV systems using amorphous silicone solar cells are designed and evaluated by using LCA. Especially, amorphous silicone solar cells have specialty in temperature, cold desert, Gobi desert and hot desert, Sahara desert are assumed. Table 1 shows geographic information of two deserts. For the comparison, case study of poly-crystalline silicon module was referred[1].

Table 1 Geographical information of Gobi and Sahara desert [2]

Area	Average temp. [°C]	Irradiation [kWh/m^2/year]				
		Tilt angle: 0°	10°	20°	30°	40°
Sahara desert (Nema, Mauritania)	30.4	7.36	7.55	7.60	7.44	7.01
Gobi desert (Hohhot, China)	5.8	4.66	5.08	5.38	5.55	5.58

3. METHODOLOGY OF EVALUATION

3.1 Life-Cycle Assessment

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 this method. This index is defined by following equations.

Generation cost [cent/kWh]=$C_{total}/G_{pv} x10^2$ (detail equations are spared)

C_{total}:total annual cost [MUSD/year]

G_{pv}: annual power generation [GWh/year]

Table 2 Kaneka and Kyocera module specification

Module	Kyocera KC120S (Poly-crystalline silicon)	Kaneka LSU (Amorphous silicon)
Nominal power	120 W	58 W
Efficiency of module	12.8 %	6.9 %
Height, Width	0.971 m x 0.966	920 mm, 920 mm
Weight	11.9 kg	12.5 kg
Coefficient of power	-0.50 %/°C	-0.22 %/°C

Ref: Photon int’l magazine

3.2 Case Studies

Case studies were assumed for four cases. Two cases were using a commercial poly-crystalline silicon solar cell module. Other two cases were a commercial amorphous silicon solar cell module. Both cases were assumed in Gobi and Sahara desert. The module specifications used in this study are shown in Table 2.

4. SYSTEM ASSUMPTION

1) 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.
2) South-faced fixed flat array structures and foundations are designed. Wind pressure and earthquake are also taken into account.
3) Considering cell temperature factors, degradation factors and inverter matching factors, system performance ratio is assumed. Poly-Si in Sahara: 0.69, A-Si in Sahara: 0.73 , Poly-Si in Gobi: 0.78, A-Si in Gobi:0.77.
4) The system lifetime is assumed to be 30 years.
5) Module price is fixed. Modules in practical use are assumed 4.0 USD/W. Thin-film module price in near future is supposed at 1.0 USD/W.
6) Inverter price and array tilt angle are given as valuable parameters. The four levels of inverter unit price of 500kW is also set to 0.136 [MUSD] for module price 4.0 USD/W, 0.159 for 3.0, 0.181 for 2.0, 0.204 for 1.0. Interest rate is assumed to be 3%/year. Currency exchange rate is 120 yen/USD.
7) Land preparation is considered.
8) Array support and foundation are produced in installation site, and other system components such as modules, cables and inverters are manufactured in Japan or Europ. All the components are transported to the installation site by marine and land transport. In this case study, land transport cost is not included.
9) Operation and maintenance are calculated in view of experience of real PV system model, or PV-USA project [3].
10) Three shifts of three operator team work in 100MW PV station. One team works in maintenance, and the other teams operate for alternation.
11) Concerning labor cost, different labor requirement for system construction was

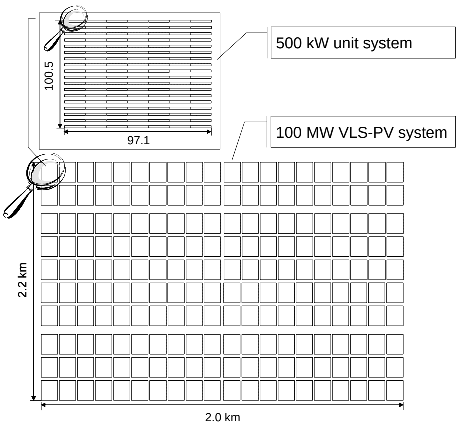

Fig.1 Unit layout for 100 MW system for amorphous Si solar cells

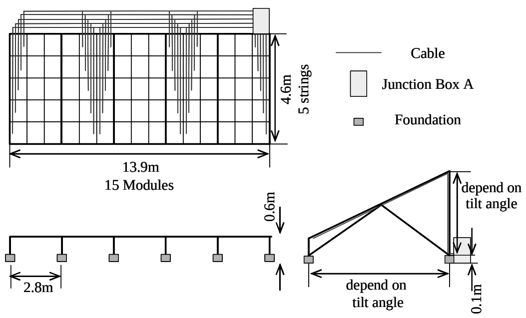

Fig.2 Array support design for amorphous Si cells

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.

12) Decommission stage is not included in this study.

5. DESIGNING VLS-PV SYSTEMS

5.1 Array support structure and foundation

Fig.2 shows the basic structure of array support for 30 degree tilt angle. Top of foundation form ground is 0.1 m and the lowest position of module 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 (based upon the Design standard of structure steel [10] by the Japanese Society of Architecture).

Cubicle foundations made of concrete are applied. Its rectangular solid is about 0.8 m each considering the design standard of support structure for power transmission by the Institute of Electrical Engineering in Japan. Fig.1 shows layout of array unit.

5.2 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-JIS.

5.3 Transmission

Electric transmission system is assumed 100 km, 2 channels and 110 kV for connecting to existing transmission. It consists of steel towers, foundations, cables and grand wires. They are considered wind velocity 42 m/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

A life-cycle of Poly crystalline silicon and amorphous silicon 100MW VLS-PV systems in the Gobi and Sahara deserts were evaluated in terms of life-cycle cost. Summary of results are shown in Table 3. Table 4 shows annual power generation and system capacity of each system.

6.1 System Component

Table 3 shows example of results. a-Si system required 3.0 km^2 in Sahara and 4.4 km^2 in Gobi desert. These are twice as much as poly crystalline case. Array support requirement is 19 thousand ton steel, and foundation needed 252 thousand ton concrete. Land requirement is considered due to spacing between PV arrays.

6.2 Cost Estimation

In this study, both investment cost and O&M cost of 100MW PV system for each installation systems are estimated to obtain generation cost. Total investment cost includes labor cost for system construction as well as system component cost.

In the Gobi desert case, there is a difference between poly-Si and a-Si system, but it’s not so much big. On the other hand, generation costs of both module systems are almost same. In addition, generation cost of a-Si system is lower than poly-Si system at 4 USD/W

Table 3 System components and Generation cost at optimum tilt angle (30° in Gobi, 20° in Sahara)

Module	KC120S (Gobi)	LSU (Gobi)	KC120S (Sahara)	LSU (Sahara)
Piece of Module	840 [10^3]	1,890	840	1,890
Area (30° tilt angle)	2.2 [km^2]	4.4	1.5	3.0
Array support	9,658 [ton]	19,063	9,658	19,063
Foundation	136 [kton]	252	136	252
Generation cost (Module price 4 USD/W)	17.6 [UScent/kWh]	18.6	14.6	14.4
(Module price 3 USD/W)	13.8	14.7	11.5	11.5
(Module price 2 USD/W)	10.0	10.9	8.3	8.5
(Module price 1 USD/W)	6.2	7.0	5.2	5.5

Table 4 Estimated annual power generation and system capacity

	Annual power generation [GJ]				System capacity [MW]
Tilt angle=	10	20	30	40	
Poly-Si (Gobi)	147	156	161	162	100.8
a-Si (Gobi)	158	168	173	174	109.6
Poly-Si (Sahara)	193	194	190	179	100.8
a-Si (Sahara)	223	224	220	207	109.6

module price, even though a-Si system require twice array and foundation as much as poly-Si system. If the module price reduces one USD/W, generation cost should be 5-7 UScent/kWh in desert area.

7 CONCLUSION

100MW Very Large-Scale power generation systems installed in the Gobi and Sahara desert was designed, and its potential was evaluated from different type PV modules which were poly crystalline silicon module and amorphous silicon module. Generation cost of poly-Si module was estimated 14.4 - 19.6 UScent/kWh at 4 USD/W module price, and 5.2 - 7.0 UScent/kWh at 1USD/W module price. Characteristics of amorphous silicon module system were shown in Sahara desert case study. In spite of its high required materials, generation cost is lower than poly-Si module system at 3 or 4 USD/W module price. The reason was that power generation was effected by temperature and coefficient of power. Amorphous silicone solar cells are not high efficiency. However, its character is effective and cost reducing in high temperature area.

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