SUITABLE VERY LARGE-SCALE PV (VLS-PV) SYSTEMS FOR DESERT REGIONS FROM FOUR TYPE CASE STUDIES BY USING LCA METHOD

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To save the earth from environmental issue such as grovel warming and energy problem, the authors proposed combination of environmental friendly PV system and huge and shiny desert area, and evaluated the possibility of the systems by using LCA method. As a result, 1) It has potential to solve energy issue, 2) Slow down the speed of global worming, 3) Hope low price and high efficiency PV module, 4) Lower array structure reduces steel and foundation, 5) Highest module efficiency make the most suitable system, 6) In case of same transmission length, high irradiation area such as Sahara desert is suitable, 7) Interest rate and wage effect generation cost.

Keywords: VLS-PV, desert, LCA, energy payback time, CO_2 emissions rate

INTRODUCTION

Some organizations propose 'Sustainable development' with large photovoltaic system utilizations. Especially, German advisory council on global change (WBGU) [1] estimated that solar electricity is more than two-third of world energy demand in 2100 in a sustainable development scenario. The authors propose utilization of very large-scale photovoltaic power generation (VLS-PV) systems (Fig. 1.) in desert area toward PV days when large amount of PV energy is utilized as main energy in the world.

Background

The authors focus on combination of desert and PV systems. The reasons are; 1) Desert is not only sand desert but also gravel desert, soil desert, stone desert and salt desert. Especially, gravel desert has hard and flat land area which is suitable for PV system. 2) Desert has strong irradiation. 3) Desert has big potential. For example, if PV systems are installed in Gobi desert with 50 percent space factor, it can generate world energy demand in 2000. 4) If we put an electricity grid map and a desert map on a same map, we can see transmission lines reach desert areas. It means it is not difficult to connect large PV in desert to big demand such as city. 5) PV is clean and maintenance free. From these reasons, the authors have started to find a way to resolve energy problem and environmental problem by large-scale PV utilization with support of IEA/PVPS Task 8 members.

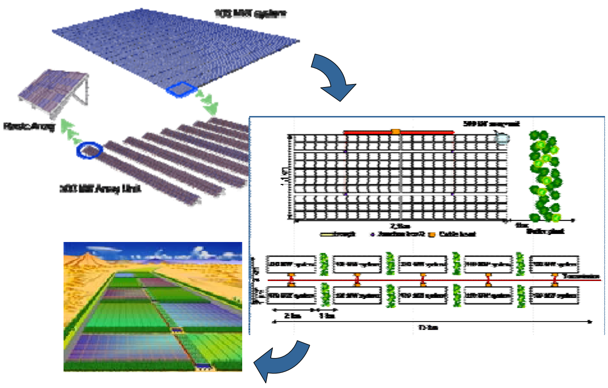

Fig. 1. Image of a VLS-PV

OBJECTIVE

This study is about possibility of combination of 'desert' which have strong irradiation and huge land area and very large scale photovoltaic power generation systems (VLS-PV). To find suitable system for desert area, four kinds of case studies were evaluated and compared.

APPROACH

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, energy payback time (EPT), CO_2 emission rate of the VLS-PV system were calculated by the method. EPT means years to recover primary energy consumption throughout its life-cycle by its own energy production. CO_2 emission rate is a useful index to know how much the PV system is effective for the global warming.

Based on concept of LCA, VLS-PV system followed these steps. Estimation items are listed in Fig. 2.

1) Plan basic assumptions such as capacity, component, transport etc.
2) Calculate irradiations for static and tracking systems
3) Design module layout, array structures, foundations, transmissions and wires
4) Calculate all materials' price, maintenance, tax, wages etc., and generation costs, energy payback time and CO_2 emissions rate.

These approaches are applied for four kinds of case studies to compare the systems. Case studies are listing below.

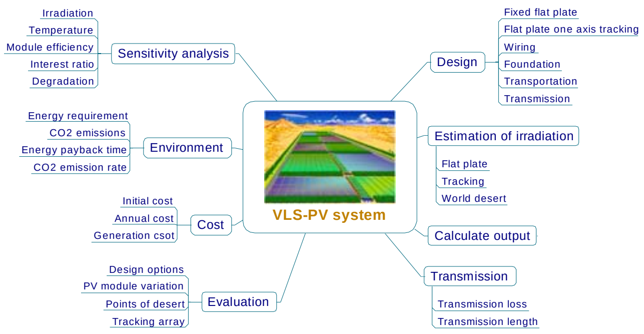

Fig. 2. Estimation items

- Case study A: Compare array structures
  Assume same system configuration and environment, evaluate three types array structures.
- Case study B: Compare module types (m-Si, a-Si, CdTe, CIS)
  Same system configuration and environment. Just change module types.
- Case study C: Compare desert regions (8 region in 6 world desert)
  Assume same system configuration, and compare environmental condition.
- Case study D: Compare fixed and tracking arrays
  Assume same environment and module, compare flat plate one axis tracking and fixed system.

INDICES

Generation cost

Generation cost concerned all components, maintenance cost and transmission losses. Annual expense of the VLS-PV [US cent/year] divided by Annual power generation [kWh/year] equal Generation cost [US cent/kWh]

Energy payback time (EPT)

EPT means years to recover primary energy consumption throughout its life-cycle by its own energy production. Total primary energy requirement of the VLS-PV throughout its life-cycle [GJ] divided by Annual primary energy reduction by using VLS-PV [GJ/year] equal EPT [year]

CO_2 emission rate

CO_2 emission rate shows amount of CO_2 produced by one kWh electricity. Total CO_2 emissions throughout its life-cycle per life-time [g-C/year] divided by Annual power generation [kWh/year].

ASSUMPTIONS

General assumptions

Economic data are shown in Table 2. The VLS-PV systems were assumed 3 %/year interest rate, 30 years life time and 1.6 %/year salvage value rate.

Table 2 Economic data used in this study

Item	Unit	Value
Salvage value rate	-	0.1
Interest rate	/year	0.03
Property tax rate	/year	0.016
Overhead expense rate	/year	0.05
Depreciation years	years	30
System lifetime	years	30

Both irradiation and ambient temperature data were referred to the World Irradiation Data Book [2]. In-plain irradiation data was calculated by using the r_b [3], Hey [4], and isotropic models [3]. Results of irradiation estimates are shown in Table 1.

An image of the VLS-PV system installed in a desert area is shown in Fig. 1. It shows an image of a basic array and a 500 kW array unit, which is about 100 m in length and width in the m-Si case. A 100 MW system consists of 200 sets of 500 kW array units.

200 sets of inverters, 208 sets of 6.6 kV circuit breakers, 5 sets of 30 MVA transformers, 18 sets of 110 kV GIS, 10 sets of 110 kV disconnecting SW, 2 sets of SVC (Static Var Compensator), and a common power board are installed in a 100 MW unit. Table 2 is information about the balance of systems (BOS) for a 100 MW system.

PV module

Four types of PV module were selected in this study. m-Si module-1 (Case study B) is 152 W, 15.8 % module efficiency and -0.49 %/ºC coefficient of power. m-Si module-2 (Case study A, C, D) is 120 W, 12.8 % and -0.5 %/ ºC. a-Si is 58 W, 6.9 % and -0.22 %/ ºC. CdTe is 65 W, 9.0 % and -0.25 %/ºC. CIS is 80 W, 11.0 % and -0.36 %/ºC. PV module prices are given 4 USD/W to 1 USD/W.

Table 1. Geographic information for world deserts

Region	Sahara	Sahara	Negev	Thar	Sonoran	Great Sandy	Gobi	Gobi
Location	Nema 16°N 7°W	Ouarza-zate 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	Dalan-zadgad 43°N 104°E
Ambient temperature	30.2 [°C]	19.2	18.9	26.9	18.4	26.1	5.8	3.5
Global	2688	2042	1943	2173	1998	2345	1702	1570
Tilt angle=10°	2750	2159	2042	2301	2100	2418	1848	1736
Tilt angle=20°	2769	2235	2104	2381	2170	2451	1958	1865
Tilt angle=30°	2721	2254	2115	2407	2184	2422	2020	1949
Tilt angle=40°	2604	2221	2075	2374	2148	2334	2031	1985
Tracking (One axis flat plate)	3707	2882	2751	3007	2743	3324	2408	2350

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

Array design

Fig. 3. shows the basic structures of array supports for a 30 degree tilt angle. 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 42 m/s (based upon the design standard of structure steel by the Japanese Society of Architecture). Cubicle foundations made of concrete are applied. The rectangular solids are about 1.0 m each, considering the design standard of support structure for power transmission by the Institute of Electrical Engineering in Japan. Material composition of the concrete is determined in order to obtain 240 kg/cm^2 of concrete strength.

Fig. 4. shows image of tracking array system. The simplest one axis sun tracking PV systems consists of PV module mounted on horizontal axis that rotate from east to west in synchronization with the sun's position in the sky.

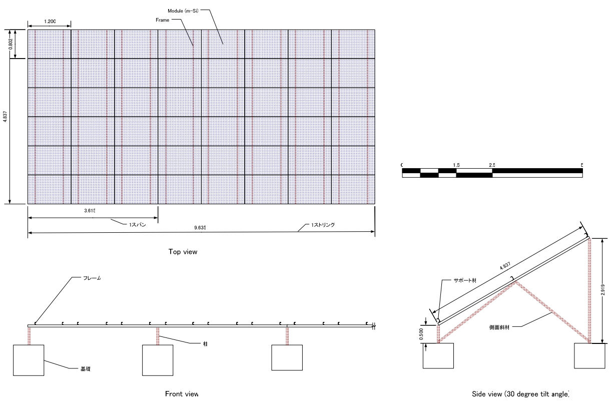

Fig. 3. Array design image for m-Si

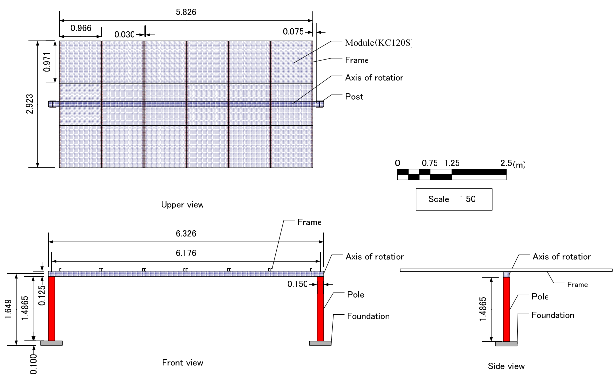

Fig. 4. Array design image for one axis sun tracking system

Wiring

The short and simple wiring is designed in order to prevent miswiring. The cable is considered current capacity to make the voltage drop less than 4%. It is determined from Japan Industrial Standards-JIS.

Transmission

The electric transmission system is assumed to be 100 km, 2 channels, and 110 kV for connecting to existing transmission. It consists of steel towers, foundations, cables, and ground wires. They consider a wind velocity 42 m/s. After calculations, transmission lines and ground wires are decided at TACSR 410 sq and AC 70 sq. An expert of utility company designed the transmission towers. 22.0 ton steel tower and 22.1 m^3 foundation are required for each 334 towers for 100 km transmission. Transmission loss is also considered. Details of transmission loss have been discussed in previous paper [5].

RESULT OF CASE STUDIES

Case study A

Three types of arrays which are high, moderate and low array structure were designed, and assumed to be installed in the Gobi desert in China. At the optimum tilt angle of generation cost (30 degree), generation cost of high array structure was 15.5 UScent/kWh (3 USD/W module price), EPT was 2.3 yeas and CO_2 emission rate was 15.1 g-C/kWh. Moderate was 15.5 UScent/kWh, 2.2 year and 15.0 g-C/kWh. Low array structure was 15.4 UScent/kWh, 2.2 year and 14.2 g-C/kWh. Therefore, in case of same tilt angle, lower array structure was suitable for VLS-PV system.

Case study B

Table 3 shows the results of generation cost of the 100 MW VLS-PV systems with 100 km transmission line in the Gobi desert in China. These results were obtained by dividing annual cost by power generation.

Table 3. Generation cost at 30 degree tilt angle [UScent/kWh]

	m-Si	a-Si	CdTe	CIS
Module price = 1 USD/W	7.0	8.2	7.9	7.6
Module price = 2 USD/W	11.1	12.3	12.1	11.7
Module price = 3 USD/W	15.2	16.4	16.2	15.8
Module price = 4 USD/W	19.3	20.6	20.4	19.9

Fig. 5. shows the required energy and energy payback time of each system. For the comparison, energy requirements were normalized at 100 MW. With multi crystalline silicon solar modules, the EPT was 1.8 years, 3.0 years of EPT were obtained for amorphous silicon solar modules, 2.4 year of EPT for CdTe PV modules, and 2.0 year of EPT for CIS PV modules.

Four kinds of PV modules were assumed for 100 MW VLS-PV systems, and their CO_2 emissions were estimated as shown in Fig. 6. It was 11.7 g-C/kWh for multi crystalline silicon, 20.2 for amorphous silicon, 17.5 for CdTe, and 14.0 for CIS module technology. The majority of all systems is the array support. High module efficiency can reduce CO_2 emissions rates because it can reduce array support structures and foundations that require much energy to produce.

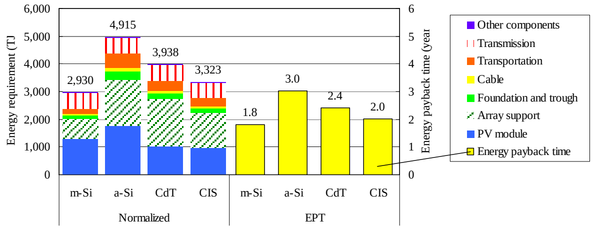

Fig. 5. Energy requirement and EPT

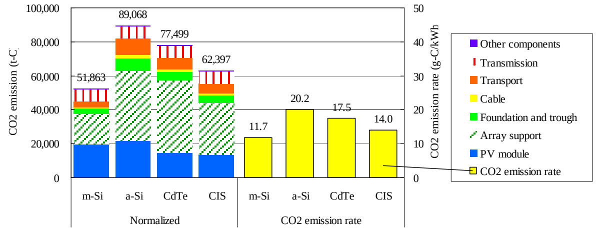

Fig. 6. CO_2 emission and CO_2 emission rate

Case study C

Case study C was studied for economic analysis. Fig. 7. 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 regions. Irradiation in Sahara is higher than Gobi, but generation cost is similar. Generation cost of Negev and Great sandy is higher than others. Because these country's wage is high.

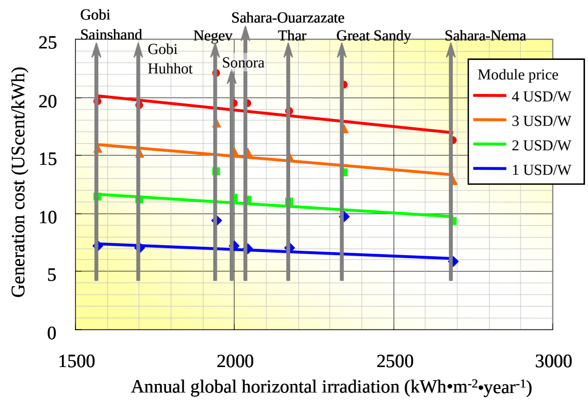

Fig. 7. Generation cost of VLS-PV in world desert

Case study D

Table 4 is a result of comparison between fixed flat plate system and one axis sun tracking system. Tracking system can reduce 10 to 15 % of generation cost, even though generation cost of tracking system include high maintenance cost which was referred to PV USA project [6]. EPT and CO_2 emission rate of tracking system is also smaller than fixed system. But difference is not big.

Table 4 Generation cost of fixed and tracking system

PV module	m-Si (Fixed)	m-Si (Tracking)
Module price		
1 USD/W	6.8	6.3
2 USD/W	11.3	9.8
3 USD/W	15.4	13.2
4 USD/W	19.5	16.7
EPT [year]	2.2	2.1
CO2 emissions rate [g-C/kWh]	14.8	13.3

CONCLUSIONS

The authors proposed combination of environmental friendly PV system and huge and shiny desert area to save the earth from environmental issues. And to know suitable system configuration, over twenty case studies were evaluated by using Life-cycle analysis.

From comparative studies. Most suitable system is;

- Lower array structure
  Lower array structure reduce steel and foundation. It is lower cost and lower environmental pollution in case of low land cost.
- Higher efficiency module
  Efficiency is dominant factor of cost, energy and CO_2 estimation.
- Install in higher irradiation area
  In case of same transmission length, high irradiation area such as Sahara desert is suitable
- A tracking system has a potential
  Tracking system generate much electricity than constructing the system.

From all case studies;

- It has potential to resolve environmental problem
  Energy requirement to produce the system is equal to power production in two to three years.
- Slow down the speed of global worming
  CO_2 emissions rate was estimated 10-20 g-C/kWh. It is much smaller than Oil fired plant (200 g-C/kWh)
- Hope low price and high efficiency PV module
  m-Si is the most suitable in this study. However, generation cost is still high (20 UScent/kWh) in case of present module price of 4 USD/W.

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