A PRELIMINARY STUDY ON POTENTIAL FOR VERY LARGE-SCALE PV (VLS-PV) SYSTEM ON THE WORLD DESERTS

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ABSTRACT: A 100MW very large-scale photovoltaic power generation (VLS-PV) system is designed assuming that it is installed on the Gobi desert, which is one of major deserts in the world. PV array is dimensioned in detail in terms of array layout, support, foundation, wiring and so on. Then energy payback time (EPT), life-cycle CO_2 emission rate and generation cost of the system are estimated based on the methodology of life-cycle analysis (LCA). As a result of the estimation, 1.7 year of EPT and 12 g-C/kWh of CO_2 emission rate are obtained. These show that VLS-PV on the Gobi desert would be very promising for the global energy and environmental issues. Assuming PV module price of 1 US$/W, system lifetime of 30 years and interest rate of 3%, the generation cost is calculated as 6.1 cent/kWh.
Keywords: PV System – 1: Economic Analysis – 2: Environment Effect – 3.

INTRODUCTION

Recently, world energy demand has been rapidly expanding due to the world economic growth and population increase, especially in developing countries. Though more energy will be required to meet the increasing energy demand, there will be serious problems such as world energy supply problem and the global environmental issue. The need for nuclear power will enlarge as one of major options, however difficulties in its siting are becoming more and more notable at the same time. Renewable energy is expected to have large potential as an alternative energy resource without constraint on energy supply or greenhouse gas emissions such as CO_2. One of promising renewable energy is solar energy. 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 dealing with a very large photovoltaic power generation (VLS-PV) system on desert on a very large scale. Even the Gobi desert that locates on high latitude has more irradiation (4.4 kWh/m^2/d) than Tokyo (3.5 kWh/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). However, PV system requires a great deal of energy input as well as money throughout its life-cycle such as production, transportation and construction. The purpose of this study is to design a VLS-PV System on the Gobi desert and to evaluate its potential from economic and environmental viewpoints.

METHODOLOGY OF EVALUATION

A methodology of "Life-Cycle Analysis (LCA)" has been employed in this study to evaluate the potential of VLS-PV system in detail. The LCA is a major tool to evaluate environmental impact of product throughout their life-cycle. The requirement of energy and materials is estimated for life-cycle of designed VLS-PV. It is manufacture and transportation of system components, system construction, and operation. Then three indices, i.e., Energy Payback Time (EPT), life-cycle CO_2 emission rate and generation cost are calculated. They are defined by following equations.

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

$$\text{EPT(Year)} = \frac{\text{Total primary energy requirement throughout its life cycle [kWh]}}{\text{Annual power generation [kWh/year]}}$$

EPT means years to recover primary energy consumption throughout its life-cycle by its own energy production.

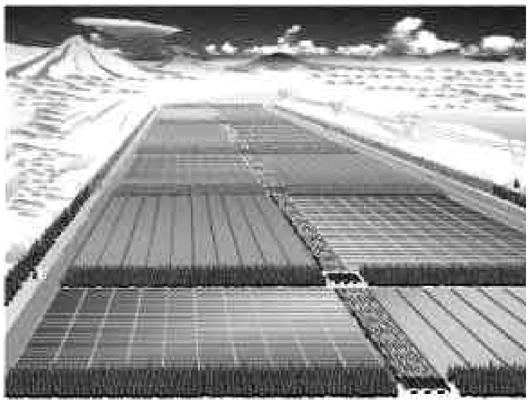

Figure 1: Image of VLS-PV system on desert

$$CO_2 \text{ Emission rate (g-C/kWh)} = \frac{\text{Total } CO_2 \text{ emission on life-cycle (g-C)}}{\text{Annual power generation [kWh/year]} \times \text{Lifetime [year]}}$$

CO_2 emission rate is a useful index to know how much the PV system is effective for the global warming.

MAJOR ASSUMPTIONS

As described above, it is considered in this study that a 100MW VLS-PV system is installed on the Gobi desert. The VLS-PV system is designed based on the following assumptions:

(1) Irradiation and ambient temperature data used for system design are those for Huh-hot (40°49' N, 89°12' E), inner-Mongolia, China, as shown in Table 1. The VLS-PV system is to be installed in a gravel desert, which consist of small rocks and covers half of Gobi desert. Sand problem is seems to be small.
(2) Total capacity is about 100MW, which consists of numbers of 500kW unit systems.
(3) South-faced fixed flat array structure is employed.
(4) Polycrystalline silicon PV module with 12.8% efficiency is employed.
(5) System performance ratio is assumed as 78% considering operating temperature, degradation, load matching factor, efficiency factor, inverter officiating and so on. The lifetime is 30 years.
(6) 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$. Inverter unit price is also set to 0.15, 0.17, 0.20, 0.22 million US$/unit for each module price. Interest rate is 3% (typical), 2% (rent from World Bank), and 6% (from ordinary financial institution). This paper is only based on 3% interest rate;
(7) Array support and foundation are produced in China, and other system components such as modules, cables and inverters are manufactured in Japan. All the components are transported to some installation site on the Gobi desert by marine and land transport. Land preparation is also considered.
(8) The method of operation and maintenance are calculated in view of experience of real PV system model, PV-USA project [1].
(9) Three shifts of three operator team work in 100MW PV station. One team works in maintenance, and the other teams operate for alternation.
(10) Total annual cost is defined by following equations: (1) Total annual cost consisting of annual depreciation cost, annual operation and maintenance cost, annual land rent and annual overhead expense; (2) Annual depreciation cost consisting of annual investment cost, annual land cost and annual property tax. (3) Annual investment cost given by total capital investment. Multiplied by annual expense rate. (Annual land rent is no charge this time.)
(11) Decommission stage is not included in this study stage now.

Table 1: Annual average data for Huh-hot

Ambient temperature	5.8 C°
In-plane irradiation	
Tilt angle=10°	1,854 kWh/m^2/yr.
Tilt angle=20°	1,964 kWh/m^2/yr.
Tilt angle=30°	2,026 kWh/m^2/yr.
Tilt angle=40°	2,037 kWh/m^2/yr.

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. Three kind of the PV module layout are prepared: (1) wide model, (2) moderate model, (3) tall model. Three design options and their wiring configuration are shown in Figures 2,3, and 4.

Based on the design standard on structures for transmissions [5], 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.

EVALUATION RESULTS

The 100MW VLS-PV system on the Gobi desert is designed on the ground of the presented assumptions. This system requires 1.4 km^2 land area at the tilt angle of 10º, 1.8 km^2 at 20º, 2.3 km^2 at 30º, and 2.6 km^2 at 40º. The amount of array support and foundation increase in

Table 3: Lifecycle stages of VLS-PV taken into account in this study

Component	PV module	Cable	Inverter	Common apparatus	Array support	Foundation
Manufacture	Japan	Japan	Japan	Japan	China	China
Transport						
Marine	O	O	O			
Land	O	O	O	O	O	O
Construction						
Land preparation						
System installation	O	O	O	O	O	O

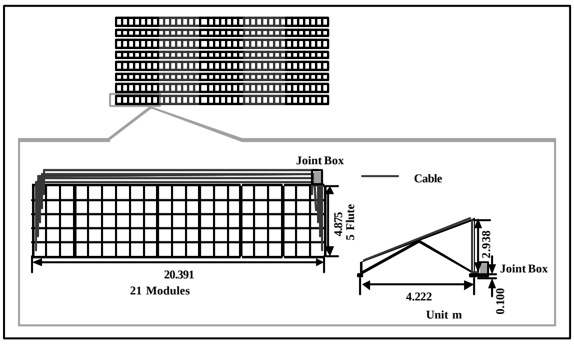

Figure 2: Design option 1 (Wide model)

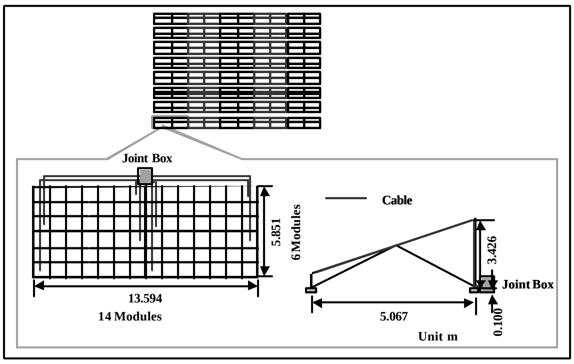

Figure 3: Design option 2 (moderate model)

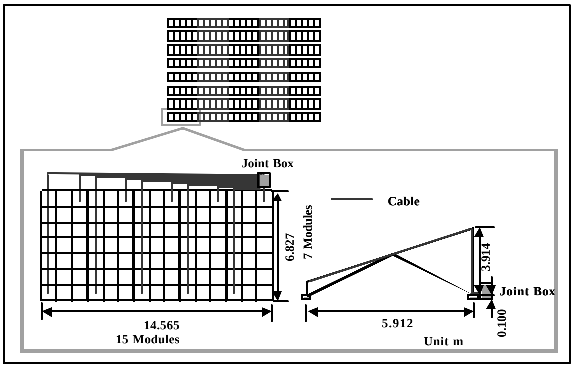

Figure 4: Design option 3 (tall model)

proportion to the tilt angle because of assumed wind pressure (42m/s). Array support requires the 9 thousand to 11 thousand ton steel, and foundation needs 90 thousand to 200 thousand ton concrete. Land requirement also increase in proportion to the tilt angles due to spacing between PV arrays. The increase in land requirement results in the increase in cable length.

The estimated results of capital investment cost for three design options show that the wide model (Design option 1) give the least capital investment cost. The generation cost of the 100MW VLS-PV system for different tilt angles and different PV module prices, assuming 30 years lifetime and 3% of annual interest rate. Annual power generation is also given also in the Figure 5. For all the cases of PV module price, the least generation cost is obtained at 30º-tilt angle, which is different from that for the most annual power generation. Though the generation cost with 4 US$/W module price corresponds to 17 cent/kWh, it is reduced to about 6.1 cent/kWh with 1 US$/W module price.

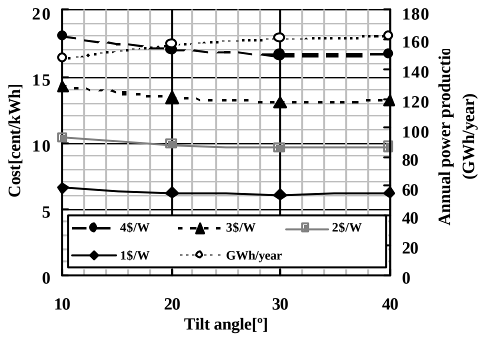

Figure 5: Generation Cost for different tilt angles

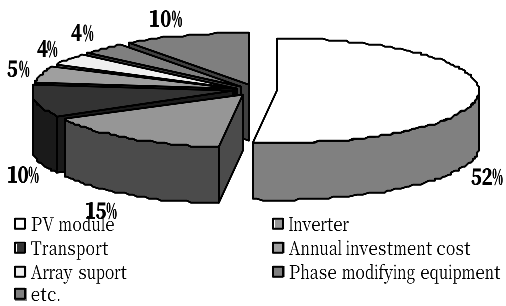

Figure 6: Break down of generation cost at 30º

Figure 6 represents the breakdown of generation cost for 1 US$/W PV module price and 30º-tilt angle by each cost component. Even though 1 US$/W PV module is assumed, its fraction reaches 52% of the total. Inverter cost accounted for 15% of all. Accordingly, the 2 thirds of generation cost is due to PV module and inverter cost.

EPT for each design option is shows in Figure 7, which suggests that 20º-tilt angle system of the Wide model gives the best EPT. It is less than 2 years, that is, the VLS-PV system can produce net power after 2-year operation.

Life-cycle CO_2 emission rate of three design options shown in Figure 8. It suggests that the best system configuration is again 20º-tilt angle and Wide model. CO_2 emission rate is 12g-C/kWh, which is much less than average CO_2 emission them power utilities in China (=260g-C/kWh).

When tilt angle is 20º, EPT and CO_2 emission have the minimum values. This is because the increase of tilt angle requires thick array support and big foundation. These need large energy in manufacturing steel or concrete. On 10º-tilt angle, EPT and CO_2 emission is larger than other tilt angle systems because of low system output energy.

SENSITIVITY ANALYSIS

In the future when the VLS-PV system is realized, PV module may efficiency than nowadays. Module efficiency is chosen as a variable parameter for the analysis. EPT decreases gradually by required energy reduction with module efficiency improvement as shown in figure 9.

Energy Payback Time and CO_2 emission rate also decreases gradually by the same reason. The figure illustrates that those values at 20% module efficiency are

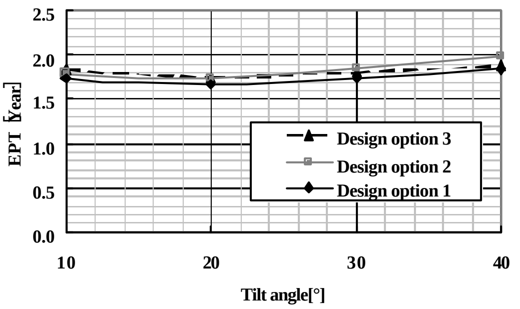

Figure 7: Energy pay back time of 3 design options (Wide model)

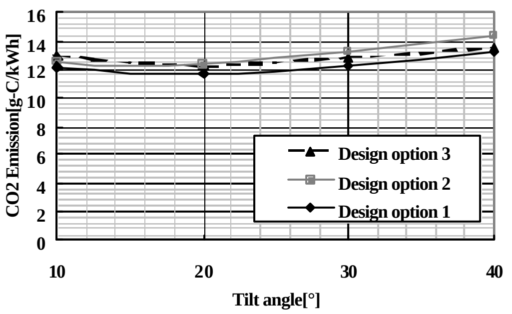

Figure 8: CO_2 emission rate of 3 design options (Wide model)

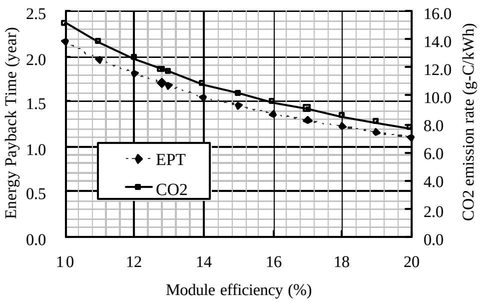

Figure 9: EPT and CO_2 emission rate for different levels of module efficiency

about half of values at 10% module efficiency.

Cost reduction by an increase in module efficiency is observed very small. The largest cost component, module cost does not vary because it is specified in $ per watt in this study.

In addition, module efficiency increase makes only array support and foundation cost decrease. Their costs are only 5% of the total, the decrease at their costs give a small influence in generation cost.

On the other hand, array support and foundation require big energy and CO_2 emission, these are about 50% each of the total. Therefore, module efficiency increase makes decrease primary energy and CO_2 output apparently.

CONCLUSION

A 100MW VLS-PV system installed on the Gobi desert is designed in detail and its potential is evaluated from economic and environmental viewpoints. Both EPT and life-cycle CO_2 emission rate suggest that large-scale introduction of PV technology on the Gobi desert is quite promising for energy resource saving and the global environmental issues. Furthermore, assuming 1 US$/W of PV module price and 3% of annual interest rate, generation cost of the VLS-PV system is estimated 6.1 cent/kWh.

The authors are also planning to design and evaluate the VLS-PV system installed on deserts with other advanced technologies such as CdS and amorphous and on other desert by applying the same approach used in this study. There also seem to be a basic question whether thin film modules are appropriate or not for systems on deserts. Some other additional topics may be considered such as regional utilization of generated electricity or power transmission. One of possible candidates may be on irrigation system to step suppress desertification. This simulation also does not include a decommission stage at the moment. It is also essential components, and it will be included in the near future.

REFERENCES

[1] C.Jennings, A.B.Reyes & K.P.O', Brien PVUSA utility-scale system capital and maintenance costs, WCPEC-1, Dec, 5-9, 1994, Hawaii.
[2] Technologies based on Life Cycle CO_2 Emissions
[3] Japan Weather Association, World Irradiation Data Book, FY1991 NEDO Contract Report
[4] Design Standard for Steel Structures, Architectural Institute of Japan
[5] Design Standard on Structures for Transmissions, JEC-127, Standards of The Japanese Electrotechnical Committee