TOWARD LARGE-SCALE PV POWER GENERATION

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ABSTRACT

This paper describes recent progresses mainly in Task VIII: Study on Very Large Scale Photovoltaic Power Generation “VLS-PV” System as a part of IEA PVPS Programme, which is international R&D collaboration programme organised by International Energy Agency. This Task discusses about large PV installation up to 1 GW in world desert areas. A preliminary feasibility study has already shown a bright future. Since a large scale PV system installation may affect its surroundings, the study covered the various key aspects of the VLS-PV such as PV technology, system configuration, system cost structure as well as environmental issues, socio-economic issues, economic/financial issues, institutional/ organisational issues. Some of studied results and tentative suggestions are explained.

INTRODUCTION

Very Large Scale Photovoltaic Power Generation systems - VLS-PV, it may be pointed out that it is a kind of dream! This is not a story at the present phase. This deals with the future tense of human society.

It might require a lot of imaginations. It is felt that a kind of dream or imagination is really welcome to this task and is worth while to discuss them for the future generation, children or grand-children. People have to imagine their lives after 30 years or 50 years, even 100 years since energy technology requires a longer lead-time to reach. In this sense, studies in terms of VLS-PV will include plant design by extending present technologies as well as to discuss basic requirements for PV energy in the future energy-supplying structure, social impacts to regions, and local and global environmental impacts.

It may be known that very large deserts in the world have a large amount of energy supplying potential. However, unfortunately, around those deserts, their population is quite limited, generally. Then, too much power generation by PV systems means worthless. Again, however, it is expected that renewable energy will be an important generation option for the 21st century as a response to global environmental problems as pointed out by COP-3 in Kyoto. It is anticipated that with global population growth and economic growth the demand and supply of energy will be very tight, especially for developing countries. New energy sources and related technologies will have to be advanced with sufficient lead-time. It is quite possible that photovoltaic technologies will provide one of the major energy sources in the future. These circumstances have become the backbone and motive force of VLS-PV works.

After the first phase of this feasibility study in 1998 [1], a framework was organised to continue this effort as IEA PVPS / Task VIII with 4 year work plan until 2002 [2]. The objective of the Task is to examine and evaluate the potential for VLS-PV systems with capacities of over-multi-megawatts to giga-watts. The key factors that enable VLS-PV to be viable will be identified and regional benefits will be clarified as well as long-term global environmental benefits. Mid-term and long-term scenario options for making VLS-PV viable will be proposed for some regions.

This international research collaboration is ongoing in co-operation with experts from the following countries: Israel, Italy, Japan, Korea, the Netherlands, Spain, United States, Mongolia.

CONCEPT AND DEFINITION OF VLS-PV

Presently, three approaches are being considered to encourage the spread and use of photovoltaic power generation systems: establishing relatively small-scale residential PV systems off and on grid, 100 to 1000 kW mid-scale systems on vacant land, and expanding multi-megawatt systems on large areas of barren, unused land.

This third category is called very large-scale photovoltaic systems (VLS-PV). In such area, systems greater than 10 MW in aggregate can readily be accommodated in relatively short periods. The definition of VLS-PV systems can be summarised as follows:

- Size may range from 10 MW to 1 GW or even a few giga-watts, consisting of one plant or an aggregation of multiple units located in the same region and operated on a collective basis.
- Amount of electricity generated by such plant is considered significant for the district, nation or

region.

- Systems can be land-based (mostly arid or semi-arid regions) or water-based (lakes, coastal, open waters), although water-based systems may not be considered in depth at present.
- Systems can be based in developing countries or developed countries, each having their special economic needs.

AVAILABILITY OF WORLD DESERTS

Solar energy is low-density energy by nature. To utilise it on a large scale, a huge land area is necessary. However, one third of the land surface on the earth is covered by very dry areas called "deserts". Among those, the total area of major 21 deserts corresponds to 17.65×10^6km^2. High-level irradiation and large spaces exist there. It is estimated that if a very small part of these areas, say 5%, was used for the installation of PV systems, the annual energy production would equal world energy consumption.

Rough estimation was made to examine desert potential by the assumptions of a 50% space factor for installing PV modules on the desert surface as the first evaluation. The total electricity production becomes $1\,942.3\times10^3$ TWh ($=6.992\times10^{21}$ J = 167 000 Mtoe), which means a level almost 18 times as much as the world primary energy supply 9 245 Mtoe (107.5×10^3 TWh $=3.871\times10^{20}$ J) in 1995.

These are quite hypothetical values, ignoring the presence of loads nearby these deserts. However, at least these indicate high potential as primary resources for developing districts located in such a solar energy rich region.

Figure 1 also shows that the Gobi desert area between the western part of China and Mongolia can generate as much electricity as the present level of world primary energy supply.

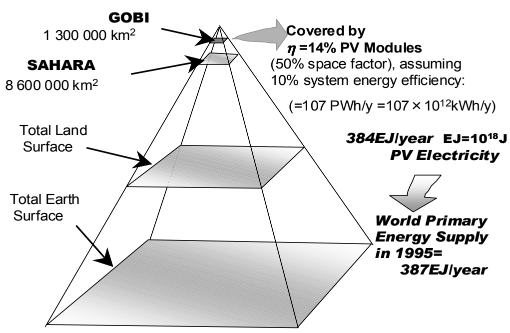


Fig.1 Solar Pyramid

WORLD 6 DESERT CASE STUDY

This case study example was originally made by the PVTEC Technical Committee on Very Large Scale PV Systems which is organised in the Photovoltaic Power Generation Technology Research Association (PVTEC) under the R&D contract with NEDO, Japan. The original study was first presented at PVSEC-9, Miyazaki, in 1996 and also shown at the International Workshop on VLS-PV Systems, Tokyo, in 1997. The examples are a part of tentative results obtained by the ongoing work and are not the latest partly.

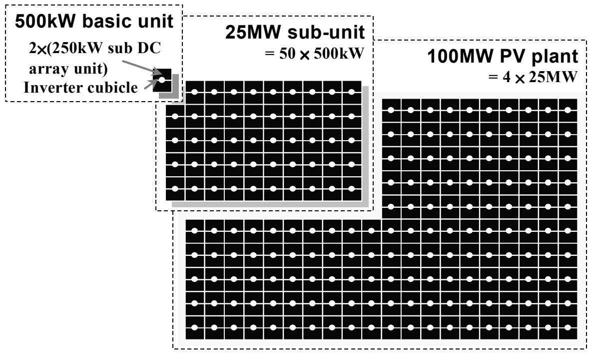


Fig.2 Schematic diagram of 100 MW PV power station [3]

The purpose of the work is to show the huge potential of PV systems in the world and to study the feasibility of large-scale PV plants. According to the tentative results of the work, possibilities are shown to realise electricity cost of 7.70 to 13.12 Yen/kWh for a 100MW plant located in any one of 6 desert sites in the world if PV module price is assumed at 100 Yen/W in consideration of site irradiation, local labour cost, and so on. In spite of the fixed flat plate, the cost can be maintained at a fairly low level. The station would comprise 10 sub-units by 20 units of 500kW optimised size sub-units as shown in **Fig. 2**.

Figure 3 also shows an example of their work. This illustrates a future image of network concept. The example assumed the Gobi desert area corresponding to Inner Mongolia in China. Power from VLS-PV will be sent to Beijing by utilising exiting and new high

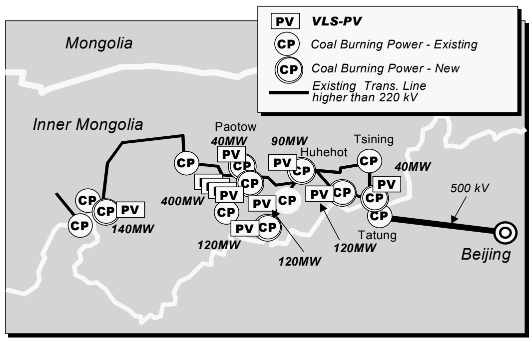


Fig.3 An example of VLS-PV concept co-oprerated with coal burning power stations and high voltage transmission lines

voltage transmission. The total capacity of VLS-PV ranges around 1 GW. National transmission lines to send coal burning power stations on colliery to Beijing already exist. If VLS-PVs are co-ordinated with those coal power stations in their operation, the utilisation factor of transmission lines will be greatly improved compared with the case of single operation by VLS-PV without storage.

VLS-PV sites illustrated in the figure are selected near to coal power stations. Then, transmission facilities already exist and the co-ordinated operation will become much easier. For forming such networks effectively, both high voltage DC transmission (HVDC) and relatively low voltage DC systems (HVDC light) seem to be feasible.

Figure 4 illustrates an image of 1 GW class PV field consisting of a number of standardised 100MW unit stations. It is assumed that a desert will be exploited in combination with agricultural development and PV plant construction.

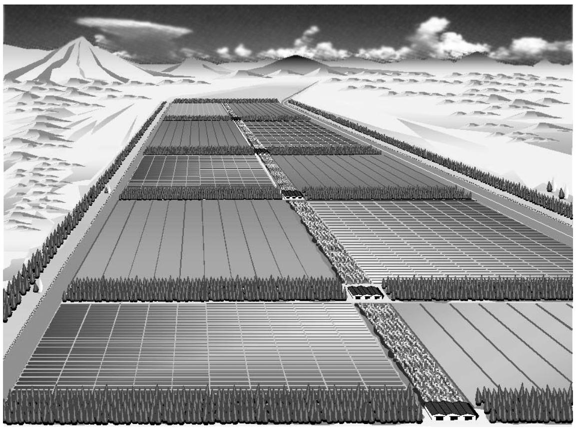


Fig.4 Image of VLS-PV System

REVIEW OF CASE STUDIES AND OTHER INFORMATION

From a preliminary analysis it has been found that the cost of power generation by VLS-PV systems appears to be promising and attractive in regions where solar irradiation is abundant as summarised in **Fig. 5**.

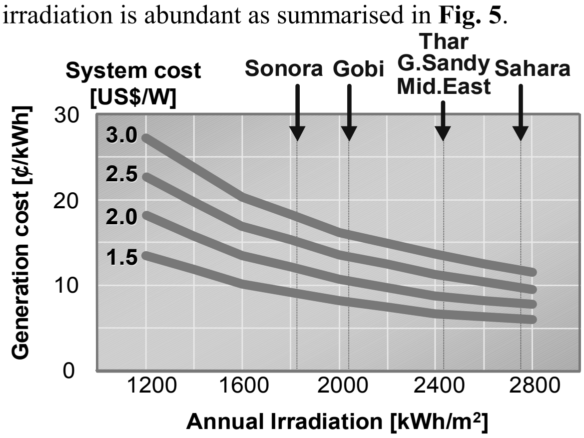


Fig.5 Indicative generation costs for different system costs and levels of annual irradiation

VLS-PV systems will affect the surrounding regions in terms of the economy, population and climate. A large-scale demand for PV systems can have positive regional impacts in terms of reducing greenhouse gas emissions and inducing employment through PV infrastructure development. Large-scale PV module production will reduce costs, making VLS-PV technology more realistic and competitive.

The value of energy from VLS-PV systems can be much enhanced if operated in conjunction with existing electricity supply infrastructure. Synergistic operation in combination with other types of power sources is also promising. A gradual evolution of multi-national networks can be expected in some regions.

At present, the PV market is supplied mainly by crystalline silicon technologies but a number of current research and development activities are likely to see break-throughs in advanced materials and PV cell fabrication processes. The forecasted price of photovoltaics ranges widely with a low of around US$ 1 per watt for thin film technology being seen as feasible. In our stance for the VLS-PV, we have decided to consider things more positively for the future.

There is evidence that international institutions are now more interested in photovoltaics for use in developing countries. There will be a need for greater use of international institutions in facilitation VLS-PV systems in developing countries.

There were other valuable case studies. Sahara Desert case in conjunction with power transmission option was studied by Italian experts. According to this suggestion, desert PV energy can be delivered to Europe through a Mediterranean power network.

Environmental impacts were also examined and analysed because of such large scale introduction to deserts. Generally speaking, PV power plants give quite positive effect to the environment such as carbon dioxide reduction, other GHG suppression, meaningful energy –pay-back-time [1], [4].

Regional socio-economical impacts such as induced employment and industrial production were also examined with respect to Gobi/China region by an approach of Input/Output Table. The tentative conclusion of this study is summarised as shown in **Table 1**. Benefits by VLS-PV seem to be unexpectedly attractive for the region.

TECHNOLOGY TRANSFER AND SUSTAINABLE DEVELOPMENT [4]

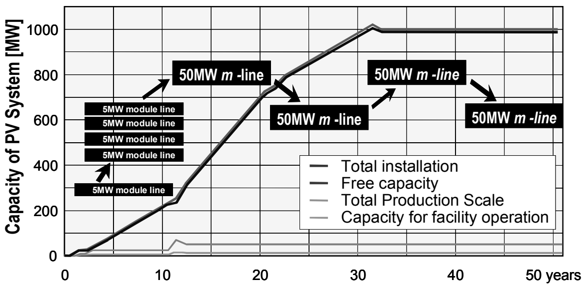
Recently, P. Menna and F. Paletta proposed technology transfer scenario, in which p-Si module assembly line will be introduced to Sahara Desert area. To extend this to sustainable scenario in the region, K. Kato submitted a case study as shown in **Fig.6**. K. Komoto

Table 1 Induced impact to Gobi/China region by the construction of 1 GW VLS-PV

Items	Impacts
Induced Production	2376 Million $* *2 times more than Final Demand: construction cost.
Induced Employees	2.58 Million Persons
Compensation for Employees	238 Million $

Assumptions:
- PV module cost = 100 ¥ = 0.77 $;
- Including regional production of PV modules and BOS as well as system construction;
- Based upon 1992 I/O table consisting of 33 sectors.

also prepared I/O analysis for this sustainable development. P. van der Vleuten provided fundamental data for the evaluation of thin film technology version.



Lifetime: PV system=20yrs., Production line=10yrs.

Fig. 6 A sustainable development scenario image by introducing PV module assembly factory into a region

According to this example, Task VIII has become real international collaborative work. Since a Mongolian expert also joined fortunately this year, information concerning real desert conditions is to be provided.

SYNTHESIS IN A SCENARIO FOR THE VIABILITY OF VLS-PV'S DEVELOPMENT

Basic case studies were reported concerning regional energy supply by VLS-PV systems in desert areas, where solar energy is abundant. According to this report, the following scenario is suggested to reach a state of large-scale PV introduction.

Generally speaking, since regions around a desert do not tend to be well industrialised, knowledge about PV technology has to be disseminated at first. To begin from this early stage, a possible scenario is suggested as shown in **Fig.8**.

The bulk systems around 100MW may be installed individually at some places at first when a phase reached Stage-3. Then, it will be interconnected with each other by power network afterward, incorporating with regional electricity demand growth. It contributes to load levelling and the improvement of power fluctuation. Finally, the district will become a large power source. A further scenario may also be followed.

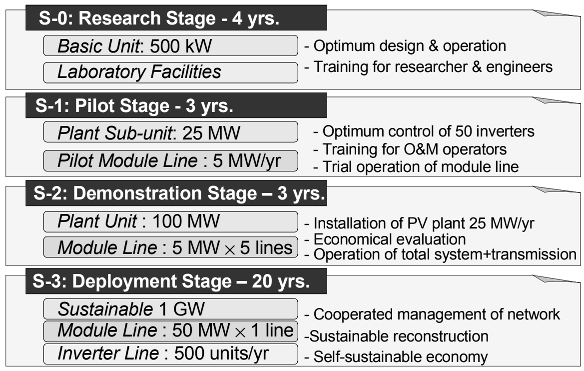


Fig.8 A possible scenario to reach giga-watt stage suggested by the PVTEC study Committee

[S-4] The regional network will be connected to a primary transmission line. Generated energy can be supplied to a load centre and industrial zone. Total use combined with other power sources and storage becomes important for matching to the demand pattern and the improvement of the capacity factor of the transmission line.

Furthermore, in the case of a south-to-north inter-tie, seasonal difference between demand and supply can be adjusted. An east-to-west tie can shift peak hours.

[S-5] Finally global network will be developed. Most of the energy consumed by human beings can be supplied by solar energy. A break-through of advanced energy transportation seeds will be expected on the long term basis such as superconducting cable, FACTS(flexible AC transmission system), chemical media, etc..

ACKNOWLEDGEMENTS

Finally, the author would like to express his thanks to all the participants of IEA PVPS / Task VIII.

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