Kingdom of Morocco

Collaboration Program with the Private Sector for Disseminating Japanese Technology fot Promotion of Concentrator Photovoltaic Power Generation System ("CPV") at Ouarzazate in Morocco

Final Report
(Public Version)

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Sumitomo Electric Industries, Ltd.

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Abbreviations

Abbreviation	English/French
CPV	concentrator photovoltaic
CSTC	Concentrated Standard Test Condition
DNI	direct normal irradiation
EPC	engineering, procurement and construction
GHI	global horizontal irradiation
GTI	global tilted irradiation
JICA	Japan International Cooperation Agency
KSG	Kirchner Solar Group GmbH
LCOE	Levelized Cost of Electricity
MAScIR	Moroccan Foundation for Advanced Science, Innovation and Research
MASEN	Moroccan Agency for Solar Energy (Renamed Moroccan Agency for Sustainable Energy in September 2016)
MEMEE	Ministère de l'Énergie, des Mines, de l'Eau et de l'Environnement
MENA	Middle East and North Africa
MoM	minutes of meeting
ODA	official development assistance
ONEE	Office National de l’Electricité et de l’Eau Potable
O&M	operation and maintenance
PCS	power conditioner system
PE	permanent establishment
PJ	project
SEI	Sumitomo Electric Industries, Ltd.
SiPV	silicon photovoltaic
STC	Standard Test Condition

1. Backdrop and Objective

1.1 Backdrop

In 2011, the wave of the Arab Spring spread through MENA countries. The Arab Spring is said to have emerged against the backdrop of high youth unemployment rates and regional or social disparities in the MENA region. Viewing these as urgent issues, the national government of Morocco is working for improvements. Japan's basic aid policy sets out sustainable economic growth backed by stable management of macro economy while striving to correct aforementioned regional and/or social disparities that can cause social instability. One significant challenge for Japan is to assist sustainable economic growth using technologies relating to solar energy, environmental measures, and resource management, among others. The Ministry of Foreign Affairs of Japan published Country Assistance Policy for the Kingdom of Morocco in May 2012. This policy sets out development and provision of industrial infrastructure with the aim of assisting the sustainable economic growth in Morocco. According to this policy, project plans will be formulated based on the comparative advantage of the technical expertise of Japanese firms.

In this situation, the introduction of concentrator photovoltaic (CPV) systems is expected to help Morocco achieve sustainable economic development through the development of efficient renewable energy because CPV systems will generate power highly efficiently at low cost in the high direct normal irradiation and high-temperature environment in the country.

Consequently, the purpose of the present project is to promote the use of the CPV system by demonstrating the high cost competitiveness and high reliability of CPV to Moroccan government officials and assess its usability in Morocco's power sector.

1.2 Objective

The project aims to improve the country's electric power supply capacity as foundation for Morocco's economic and social development by using a high-efficiency and low-cost power technology. It also aims to help Morocco meet the challenge of sustainable economic development by introducing a renewable energy development technology that makes optimal use of the country's natural environment.

1.3 Overview of the Technology for Wide Deployment

While we are working on the wide deployment of the CPV technology, expectations are high for it as the most suitable clean energy technology in the environment of Middle East and North Africa (MENA), particularly in Morocco, the host country of this project. Accordingly, this project aims to prove the power generation performance and effectiveness of the technology.

The basic operating principle of CPV is to use compound semiconductor photovoltaic cells at an extremely high power generation efficiency of over 40% to generate electricity while tracking the Sun accurately and concentrating direct sunshine through lens.

The module efficiency of CPV exceeds 30%, which is a performance level about twice that of typical crystalline silicon photovoltaic (SiPV) modules. Unlike SiPV, CPV cells exhibit almost no decline in efficiency at high temperatures. As such, expectations are high for CPV as a next-generation power generation system valid in high-temperature, high-direct normal irradiation (DNI) regions.

The project site is located in Ouarzazate, Morocco, which is the place known as the door of the Sahara. The town is in the area of the highest DNI (6.8 $kWh/m^2 \cdot day$) in the country. Accordingly, the site is ideal for CPV. However, sand dust is forecast to settle on CPV modules, which might affect the generation performance of CPV. Sumitomo Electric is studying module maintenance techniques such as cleaning methods and frequencies. After proving the effectiveness of the maintenance techniques in this project, we intend to deploy them widely.

One factor that substantially affects the amount of electricity generated by CPV is its solar tracking performance. Generally, photodetectors are mounted on solar trackers to ensure that the module surfaces are constantly perpendicular to the incident solar radiation. However, this and other conventional methods may not be adequate for solar tracking due for example to clouds. Sumitomo Electric is working on the development of a program that enables the output signal of the power conditioner system (PCS) to be fed back to the tracking system for optimal tracking for an extended period of time. After proving the performance of the program through this project, we intend to bring it into wide use.

Furthermore, we will demonstrate a generated electricity monitoring system that uses the power line communication (PLC) technology. Unlike traditional systems, this monitoring system uses direct-current wiring line for monitoring, without the need to additionally install a communication line. After verifying whether this technology is valid in the environment of Morocco, we will bring it into wide deployment.

As described above, the technologies to be brought into widespread use through this project include, in addition to CPV, those fit in the environment of the project site, such as module coating, maintenance, solar tracking, PLC, and operation thereof.

2. Project Overview

2.1. Particulars about the Demonstration Project

(1) Action policy

Facilitate Moroccan government officials to have a deeper understanding of CPV. Provide them with guidance on CPV operation and maintenance technologies. Also, help the local authorities and other people involved understand the CPV system for its wide deployment in Morocco. Additionally, assess the system's usability in the Moroccan power sector.

① Fully understand the current state of affairs regarding the development challenges facing the host country and the sector in question as well as the host country's electric power business policy. Moreover, thoroughly assess the anticipated development benefits brought about by the project.

② Thoroughly verify the comparative advantage of CPV over Si PV from the perspective of levelized cost of electricity (LCOE) determined based on the amount of electricity generation, power generation stability, maintenance and management cost, among other factors, under the weather conditions in Morocco. Provide the people involved of the host country with relevant explanations.

③ When considering the direction of post-project business development, conduct a sufficient feasibility study on the introduction of CPV systems using the host country's own funds or business investment from Japan. Work out a financing plan avoiding sole reliance on ODA funds.

④ Collect relevant information for smooth business development following the completion of the project's operations. Establish the direction of the business before the project's operations end.

(2) Operation description

① Current state of affairs of development challenges facing the area and sector in question in the project

② On-site activities

  i. Site selection and installation of demonstration CPV equipment
  ii. Proving the advantage of CPV over conventional silicon photovoltaics (Si PV) through comparison in a high-temperature and high-solar irradiation environment
  iii. Introduction of PLC monitoring system
  iv. Checking power generation stability and maintenance and management conditions after a predetermined period of time following the demonstration test
  v. Information collection and problem identification for commercialization

③ Exploring the direction of business development following the completion of the project's operations

  i. Business outline (goals, production/sales plan, financing plan, personnel development plan, local partners, etc.)
  ii. Schedule preceding commercialization

④ Clarification of development benefits expected from conducting business after the co mpletion of the project's operations

i. Groups benefiting from the business

ii. Development benefits expected from the business

⑤ Exploring the possibility of collaboration with local ODA projects

i. Need for any collaborative project

ii. Description of any collaborative project and expected benefits

(3) Area

Ouarzazate, Kingdom of Morocco

(4) Party involved of host country

MASEN

(5) Project period

From March 23, 2015 to February 28, 2017

(6) Technology for wide deployment

Concentrator photovoltaic (CPV) system

Power line communication (PLC)-based monitoring system

2.2. Demonstration System

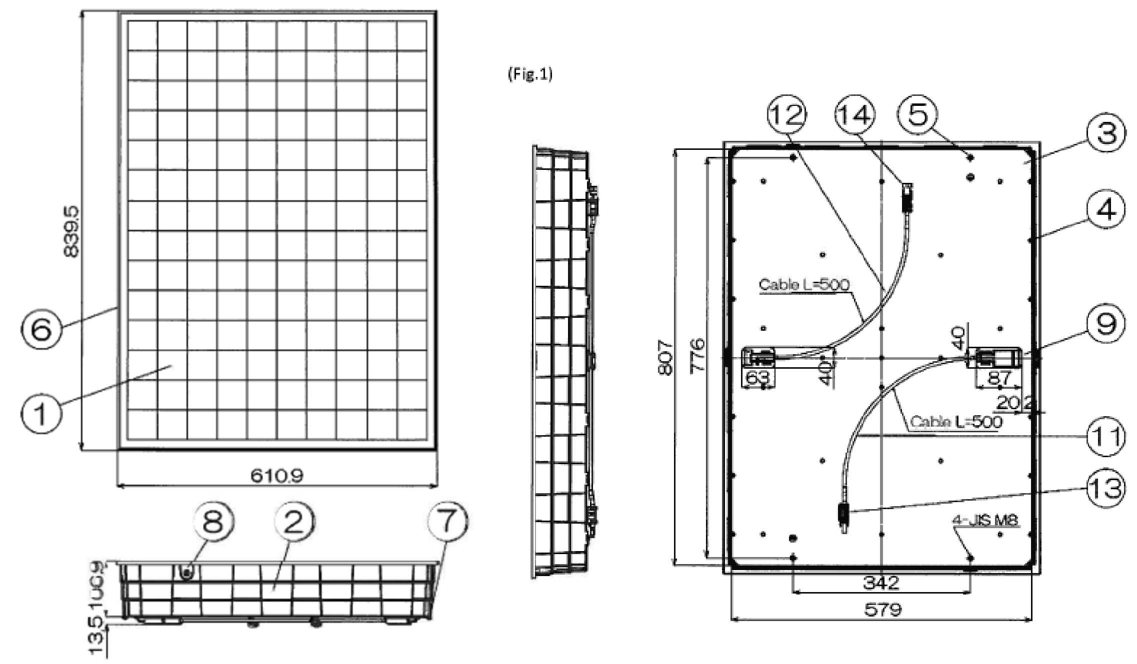
(1) Demonstration system overview

The devices constituting the demonstration system used in the present project are listed below.

- CPV modules: 144 (20 kW)
- CPV solar tracker (two-axis tracking): 1
- Si PV modules: 40 (10 kW)
  + two modules (used to supply power to measuring and monitoring system)
- Fixed mount for Si PV: 1 set (installation at 20°)
- Inverters: 2 (20 kW × 1 plus 10 kW × 1)
- Measuring and monitoring system: 1 set
- PLC-based monitoring system: 1 set
- Weather sensor: 1 set (DNI, GHI, GTI, wind direction, wind velocity, and rainfall amount)
- Load resistance: 30 kW equivalent

(2) Specifications for CPV and Si PV modules

A 21.9 kW CPV system was constructed using 144 CPV modules manufactured by Sumitomo Electric. The CPV module manufactured by Sumitomo Electric is outlined below.



Symbol	Part Name	Material	QTY
1	Lens	Low iron glass and silicone	1
2	Frame	Reinforced PBT resin	1
3	Backplate	Aluminum (Rear side: White painted)	1
4	Screw	Stainless steel	12
5	Hex nut M8	Stainless steel	4
6	Lens sealant	Silicone	1
7	Backplate sealant	Silicone	1
8	Vent	Teflon-based film	2
9	Output terminal (+)	PPE/PPO	1
10	Output terminal (-)	PPE/PPO	1
11	Cable (+)	14AWG (Black)	1
12	Cable (-)	14AWG (Black)	1
13	Waterproof connector (+)	CCT9901-2452F	1
14	Waterproof connector (-)	CCT9901-2362F	1

Figure 1 : CPV module External View

Table 1: CPV Module Specifications

CPV Specifications	
Manufacturer	Sumitomo Electric Industries, Ltd.
Model No.	sCPV04a-VN-AN
Concentration Level	520
Dimensions	839 mm (L) 610 mm (W) 120 mm (H)
Weight	8.0 kg
Output	152 W CSTC conditions: 25°C cell temperature, 1000 W/m^2 DNI, ASTM G173 AM1.5D

Si PV was used for comparison purposes, which is outlined below. We used polycrystalline Si PV modules manufactured by Trina Solar available in Morocco.

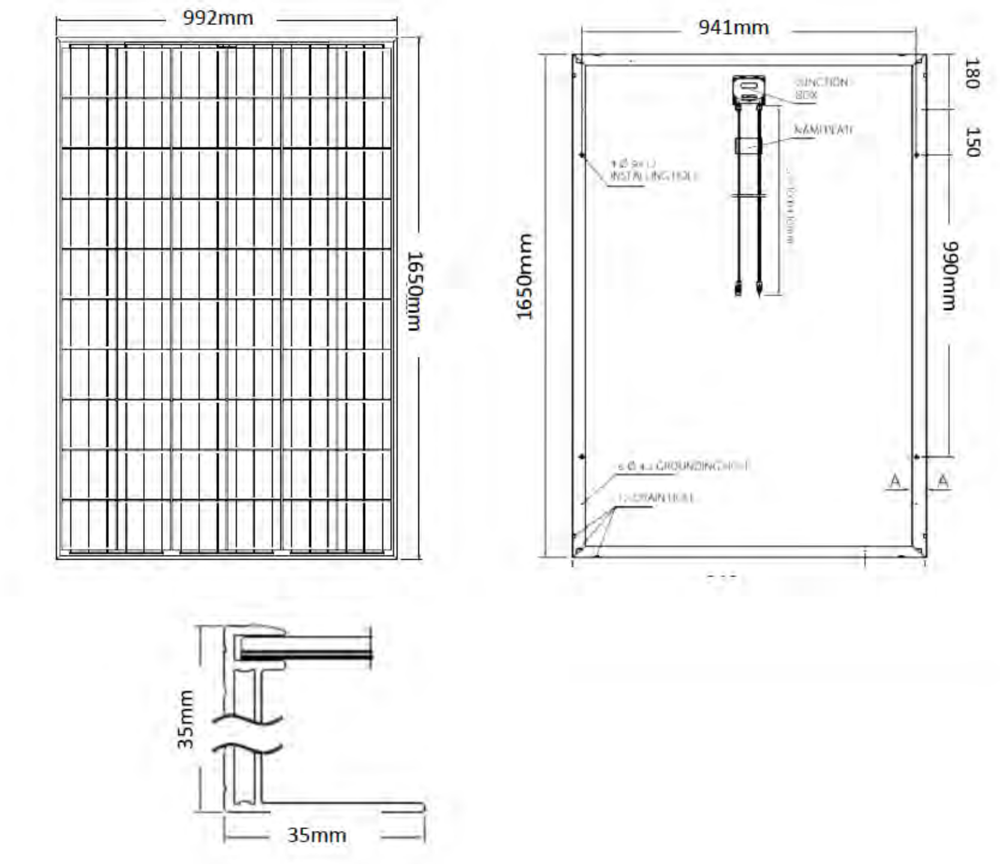


Figure 2 : Si PV Module External View

Table 2 : Si PV Module Specifications

Si PV Specifications	
Manufacturer	Trina Solar
Model No.	TSM-250PC05A
Dimensions	1,650 mm (L) 992 mm (W) 35 mm (H)
Weight	18.6 kg
Output	250 W STC conditions: 25°C cell temperature, 1,000 W/m^2 DNI, and AM1.5

(3) Specifications for solar tracker

CPV systems characteristically use solar trackers. While Sumitomo Electric has tested solar trackers, challenges associated with them were power generation losses due to poor tracking accuracy and cost. For the present demonstration, we improved solar tracking accuracy by using clock-based solar tracking complemented by photodetector-based self-correction. Moreover, we reduced construction and other costs by expanding the CPV area per solar tracker to approximately twice those of previous systems.

Another consideration was minimization of output decreases caused by sand dust settling on CPV surfaces. For this purpose, a mechanism was added to let CPV surfaces face downward, which enabled the CPV system to avoid sand dust during nighttime standby hours.

The specifications for the solar tracker are as follows:

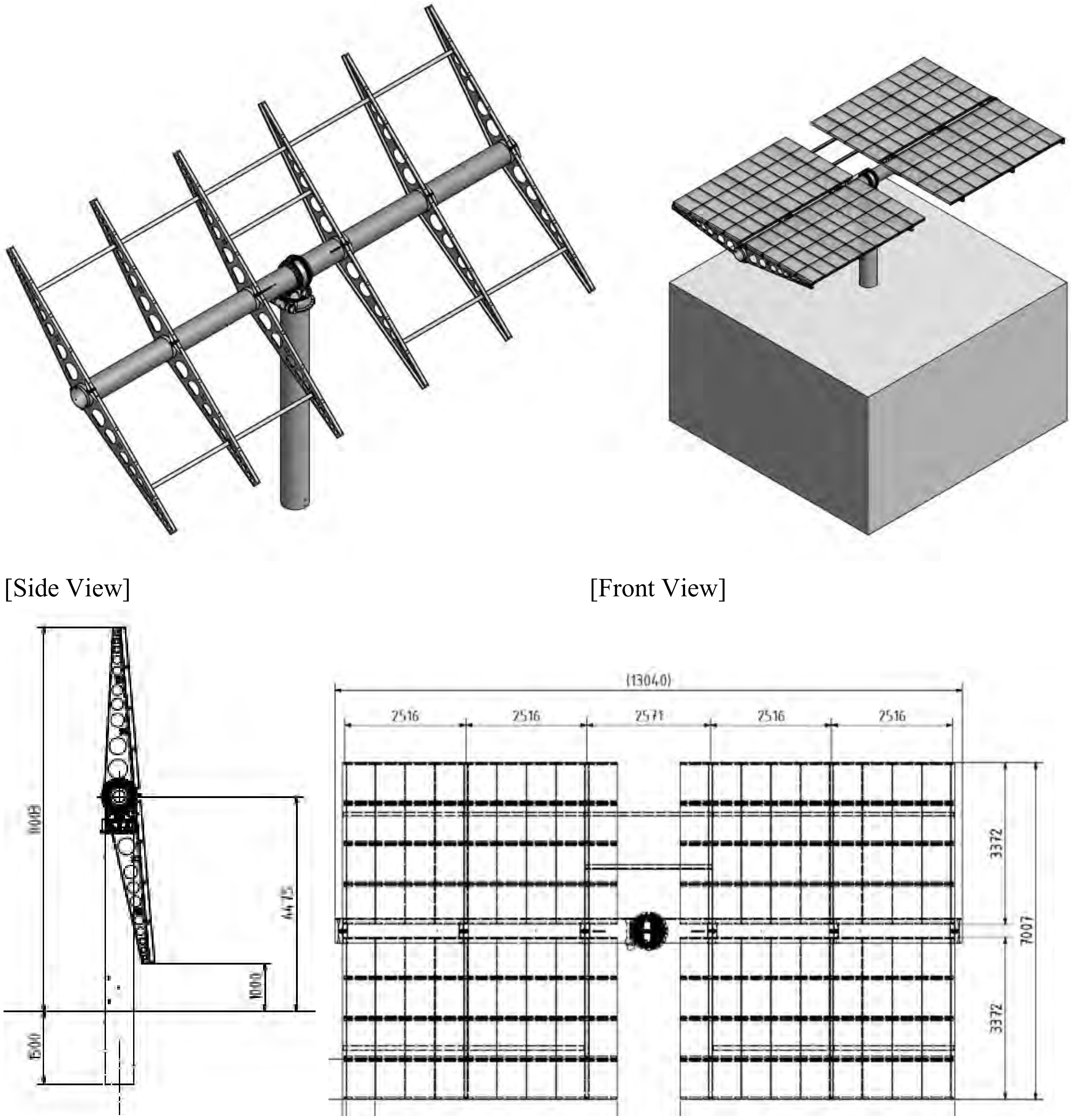


Figure 3 : Solar Tracker External View

Table 3 : Solar Tracker Specifications

Solar Tracker Specifications	
Manufacturer	Kirchner Solar Group GmbH (Germany)
Drive System	Two-axis drive system
Mount Dimensions	Mount area: 91 m^2 7,007 mm (L) 13,040 mm (W) 4,475–8,003 mm (H)
CPV mounting quantity	144 modules
Material	Hot dip galvanized steel
Tracking System	Clock (latitude, longitude, time) + Self-correction by photodetector
Driving Range (angle of elevation)	0°–85° (when generating power)
Protection from sand dust	CPV surface maintained in inverted position during nighttime

Meanwhile, a fixed mount was used to install SiPV at an angle of 20° for comparison purposes.

(4) Demonstration equipment overview

The CPV system (20 kW), Si PV system (10 kW), various weather sensors, and data acquisition system were installed at the Noor Complex R&D Platform managed by MASEN. The installation site measured approximately 30 m by 30 m. The photo shown below depicts the overall demonstration system.

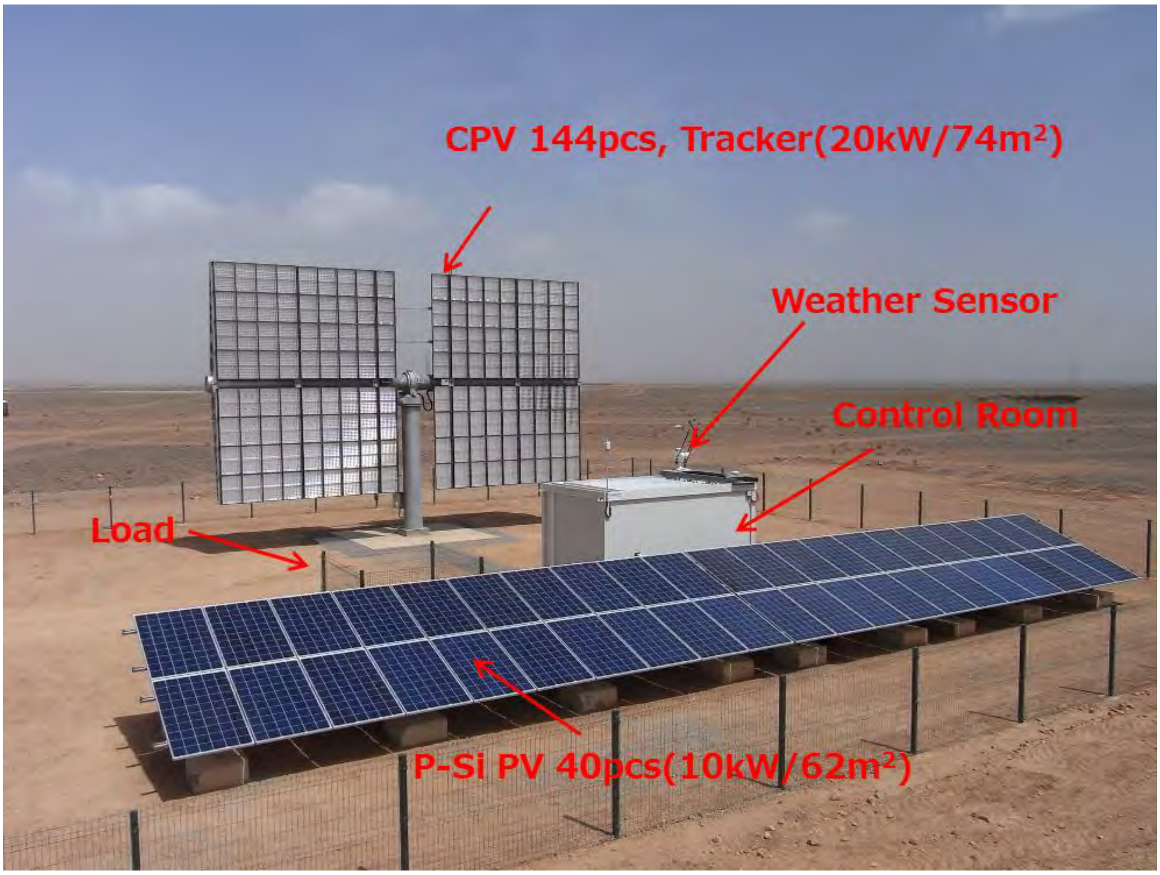
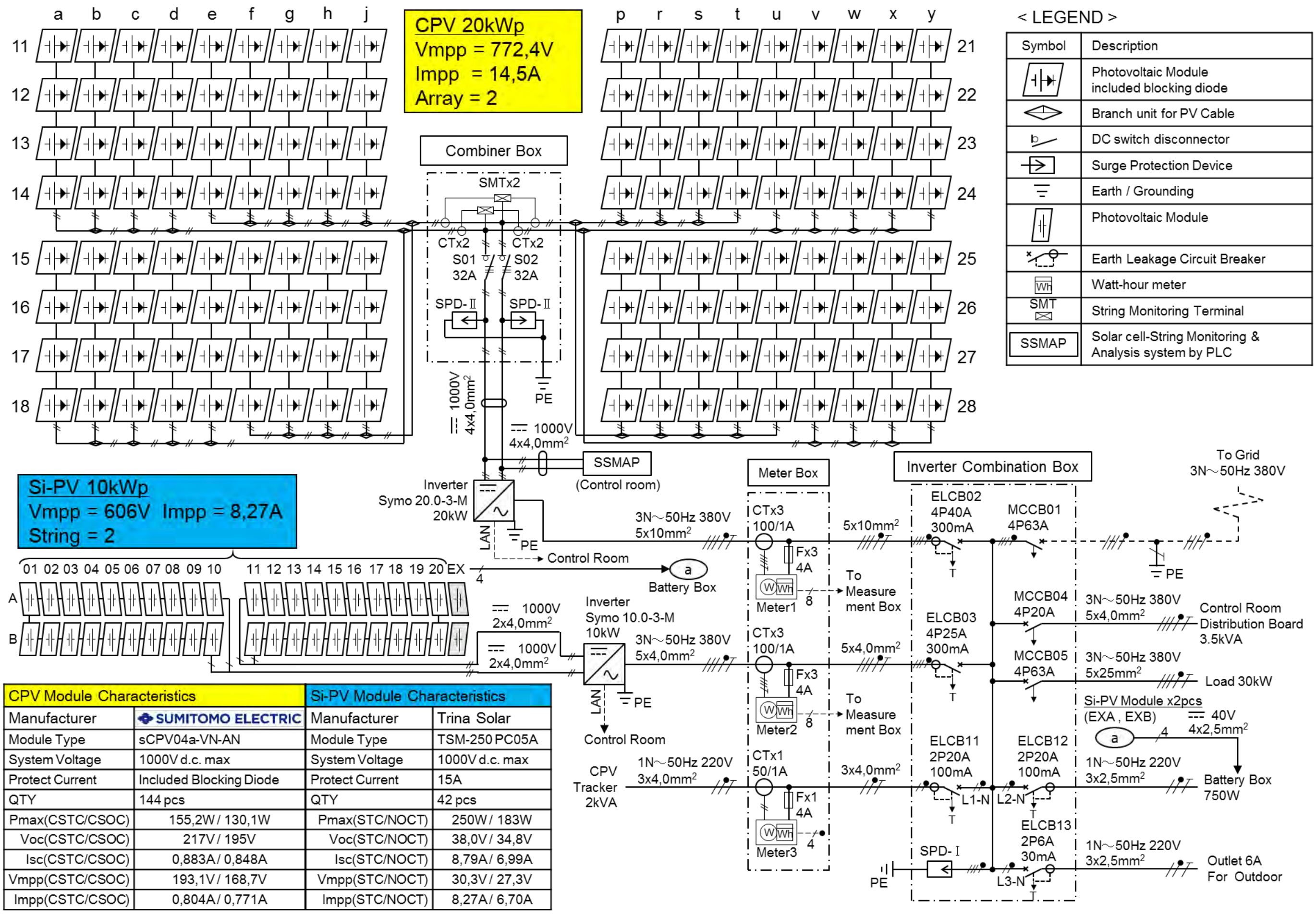


Figure 4 : The Overall Picture of Demonstration Site

SiPV, the control room, and CPV were placed from south to north in this order considering the influence of shadows. An actinometer was placed on the roof of the control room so as also to avoid the influence of shadows.

(5) Single-line system and conceptual diagrams

Shown below are single-line and conceptual diagrams for the system.



CPV Module Characteristics		Si-PV Module Characteristics	
Manufacturer	SUMITOMO ELECTRIC	Manufacturer	Trina Solar
Module Type	sCPV04a-VN-AN	Module Type	TSM-250 PC05A
System Voltage	1000V d.c. max	System Voltage	1000V d.c. max
Protect Current	Included Blocking Diode	Protect Current	15A
QTY	144 pcs	QTY	42 pcs
Pmax(CSTC/CSOC)	155,2W / 130,1W	Pmax(STC/NOCT)	250W / 183W
Voc(CSTC/CSOC)	217V / 195V	Voc(STC/NOCT)	38,0V / 34,8V
Isc(CSTC/CSOC)	0,883A / 0,848A	Isc(STC/NOCT)	8,79A / 6,99A
Vmpp(CSTC/CSOC)	193,1V / 168,7V	Vmpp(STC/NOCT)	30,3V / 27,3V
Impp(CSTC/CSOC)	0,804A / 0,771A	Impp(STC/NOCT)	8,27A / 6,70A

Figure 5 : Single Line Diagram of Demonstration System

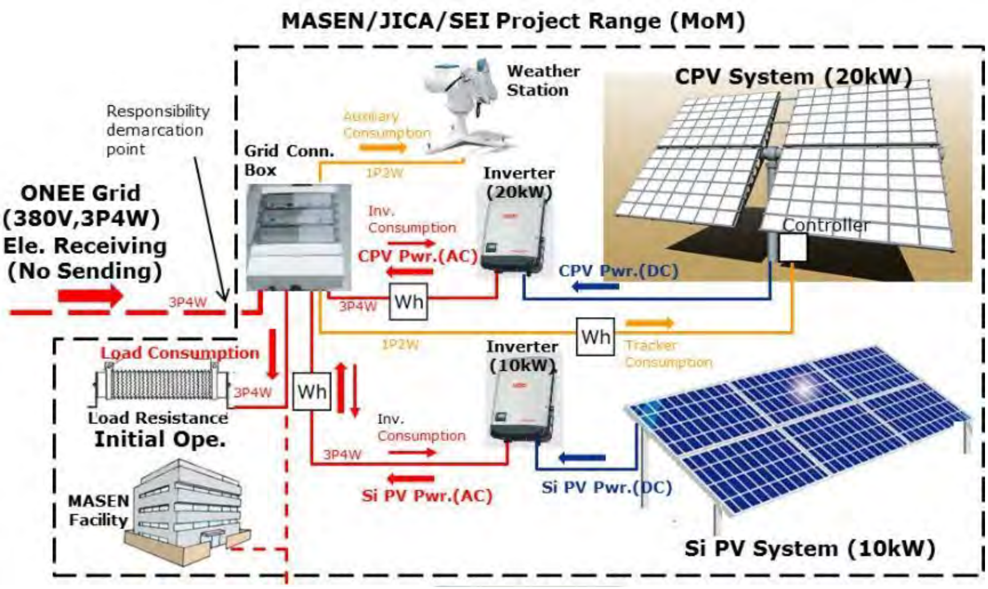


Figure 6 : Conceptional Diagram of Demonstration System

Each group of four CPV modules was connected in series, which constituted 36 groups connected in parallel. Branch cables were used to configure these into four parallel strings. A PLC-based monitoring system was provided for the set of four parallel strings. In contrast, Si PV modules were arranged into two parallel strings, each consisting of 20 modules connected in series.

The DC output from each of these systems were converted into AC by an inverter. Their respective amounts of generated electricity were measured by a wattmeter. The measuring and monitoring system collected measurement data of the amounts of generated electricity and of weather sensors and carried out automatic transmission of the collected data via the 3G network available on the site.
The demonstration system was connected to the low-voltage grid (LV 380 V) set up by MASEN within the Noor Complex R&D Platform.

2.3. Master Schedule

• From manufacturing of CPV to completion of CPV system construction

On-site activities up to the completion of the CPV system are charted below.

After the MoM was signed, we began to manufacture CPV and completed in May. During this manufacturing period, we selected a local construction company and concluded a construction contract with it. Construction began in July in line with the transportation of CPV and BOS equipment to the site. The construction was completed in early September almost as initially planned except for connection with the power grid.

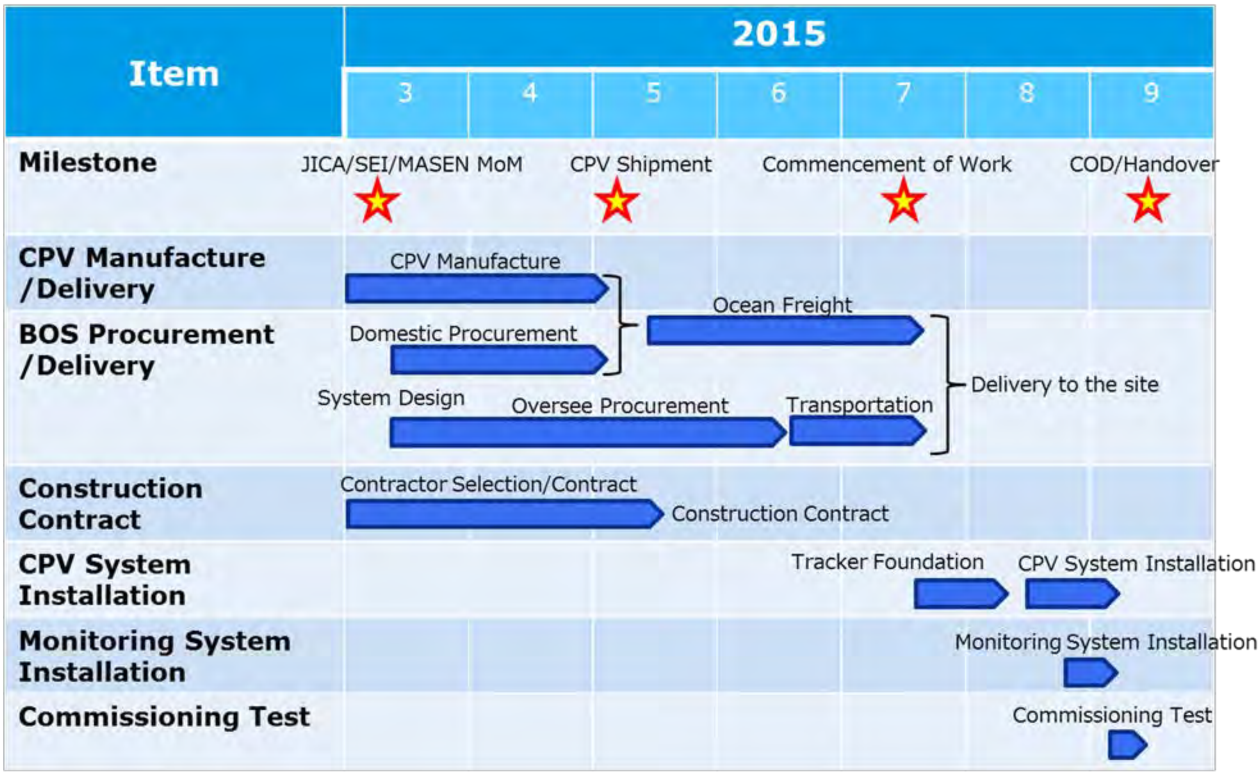


Figure 7 : Schedule from CPV manufacturing to the Completion of Construction Work

• After construction completion

The table below shows the schedule for on-site activities following the completion of the construction of the CPV system.

Power generation tests were conducted in three periods (Nov to Dec 2015, Mar to Apr 2016, and Jun to Sep 2016) without connecting to the power grid, yet instead connecting to a diesel generator as a pseudo power grid, because power grid connection could not be provided in time before the completion of the CPV system construction. Seasonal power generation data were acquired during these periods. Furthermore, operation and maintenance (O&M), including cleaning, were optimized through these periods.

The CPV system was connected to the power grid in late September of 2016. We witnessed the connection and checked the operation. Thereafter, power generation data were acquired continuously. A final check up, including visual test, parameter renewal, system operation test and power generation confirmation, was conducted on site at the end of this demonstration term in January 2017 and the CPV system was confirmed as good condition after more than a year operation.

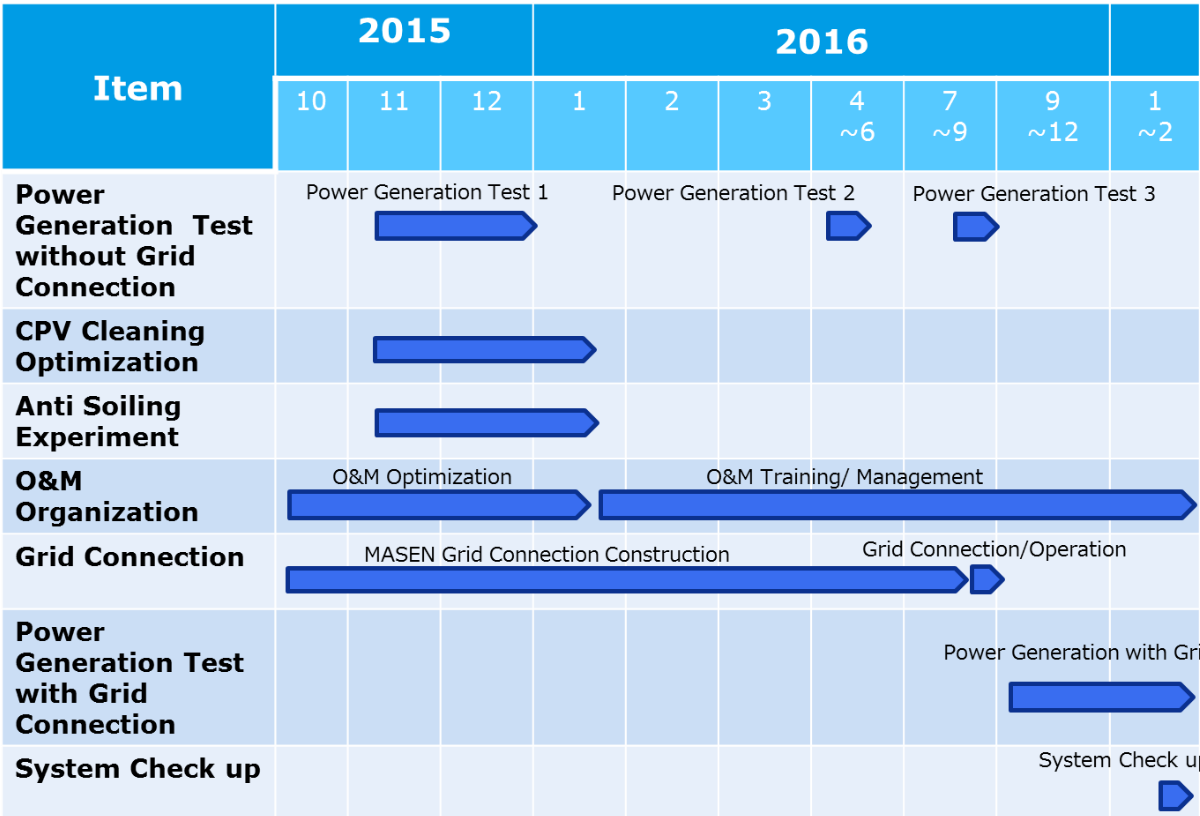


Figure 8 : Schedule Following the Completion of Construction Work

2.4. Implementation Framework

The framework formed to implement the project is as illustrated below.

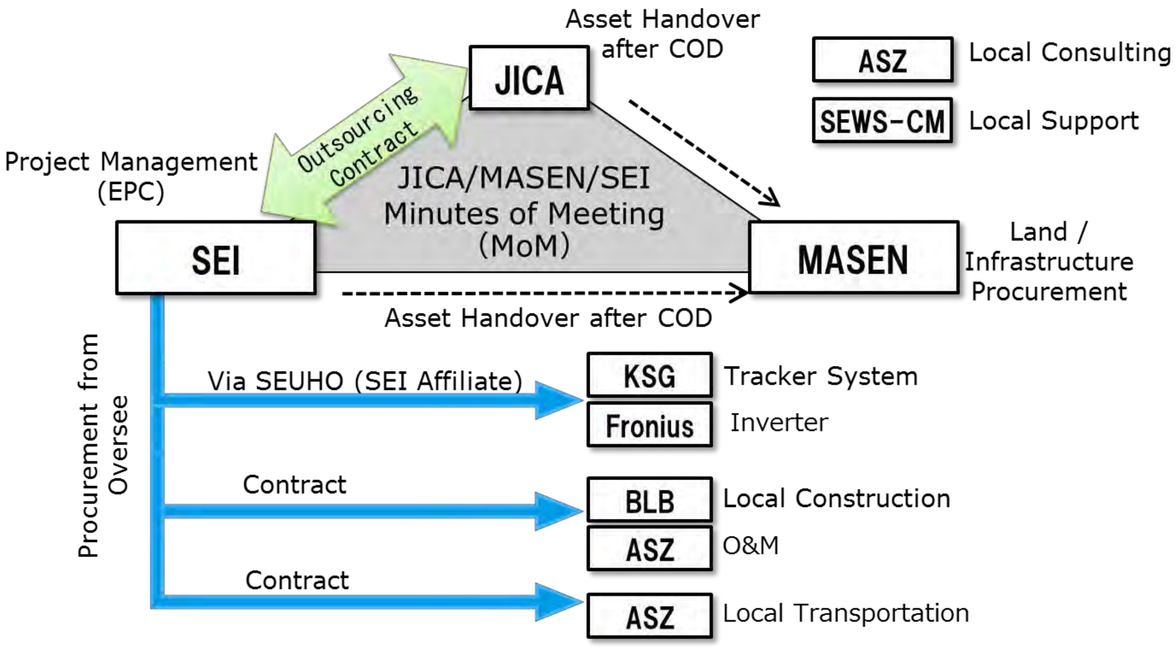


Figure 9 : The Framework of the Project

Sumitomo Electric is in charge of project engineering, construction, and procurement of equipment in accordance with the minutes of meeting among JICA, MASEN, and Sumitomo Electric. MASEN provides the required land and infrastructure.

For the purposes of engineering, construction, and equipment procurement, Sumitomo Electric hired BLB, which is a local construction company, for construction, and ASZ for assistance in local logistics such as customs clearance.

Incidentally, since Japan has no tax convention signed with Morocco, a PE tax was imposed on Sumitomo Electric without regard to the construction period. Sumitomo Electric paid the required amount of the tax to the government of Morocco.

3. ProjectResults and Activity Report

3.1. Construction

Installation work were implemented between July and September 2015. Below pictures are situation of construction.

<table>
<tr><td></td><td></td></tr>
<tr><td>Site view before construction</td><td>Mast erecting</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Tracker unloading</td><td>CPV installation</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Tracker lift up/Connection</td><td>Tracker installed</td></tr>
</table>

	
Si PV installed	Weather sensor installed
	
PLC-based monitoring system installed	Demonstration CPV system installation completed

Figure 10 : Pictures of CPV System Construction

3.2. Power Generation Demonstration

The present project has demonstrated power generation to "thoroughly verify the comparative advantage of CPV over Si PV from the perspective of levelized cost of electricity (LCOE) determined based on the amount of generated electricity, power generation stability, maintenance and management cost, among other factors, under the weather conditions in Morocco" and to "provide the people involved in the host country with relevant explanations," as stated in 2.1 (1) on page 5.

To estimate LCOE, a specified formula, as shown below, is used.

$$\mathrm{LCOE} = \frac{\text{Lifetime cost[\$]}}{\text{Lifetime generated electricity[kWh]}} = \frac{\text{Lifetime cost per nominal output[\$/kW]}}{\text{Lifetime generated electricity per nominal output[kWh/kW]}} \qquad (1)$$

$$\text{Lifetime generated electricity per nominal output[kWh/kW]}$$

$$= \sum_{n=1}^{n=\text{Operation years}} \left(\text{Annual generated electricity per nominal output[kWh/(kW)]} \times (1+\text{Deterioration rate[\%/year]})^{n-1}\right) \qquad (2)$$

Taking note of the annual generated electricity per nominal output in Equation (2) to verify the power generation demonstration in terms of LCOE, the obtained power generation demonstration data are analyzed below.

Since the power grid connection work, which Morocco was in charge, became behind the initial schedule, it was difficult to directly acquire the data of the amount of annual generated electricity. As such, we needed an alternative way. First, the amount of generated electricity per nominal output per day was calculated for days in that the demonstration experiment was conducted. Next, the annual amount of generated electricity was estimated. To acquire power generation data, we carried out demonstration power generation experiments during the following periods, connecting the photovoltaic systems to a generator which simulated the power grid.

Period 1: Nov 4, 2015–Dec 20, 2015 (for 46 days from fall to winter)
Period 2: Mar 23, 2016–Apr 14, 2016 (22 days in spring)
Period 3: Jul 18, 2016–Sep 7, 2016 (51 days in summer)
Period 4: Sep 21, 2016– (Since connection to power grid)

The use of the generator to simulate the power grid differed from the real power grid in that it was a simulated, closed and limited system. This was subject to noise amplification. As a consequence, during the demonstration experiment, the PV inverter erroneously detecting noise exhibited frequent temporary shutdowns. For this reason, data affected by problems, as mentioned above, that would never occur if the photovoltaic systems are connected to the real power grid were excluded from the acquired data to properly fulfill the purpose of this demonstration experiment. More specifically, the amount of generated electricity per day was determined after removing each system's power generation data corresponding to the above-mentioned error and shutdown hours.

The CPV system used in this demonstration experiment incorporated automatic control to ensure safety. In case of a strong wind exceeding a preset wind velocity, the CPV system would be forced into the safest retracting position. To specify a preset wind velocity, the maximum bearable wind velocity was determined based on strength calculation for the structure and foundation with a safety margin taken into account. To elucidate simple differences between the power generation technologies by processing demonstration experimental data, the amount of generated electricity per day was determined additionally excluding the power generation data corresponding to the forced position control hours, as in the aforementioned case of shutdowns of the PV inverter.

Data dated November 4, 2015 is presented below as an example of the acquired power generation data. Figure 11 plots one-day changes in solar irradiation and generated electricity per unit area. The reference solar irradiation for CPV is defined in terms of direct normal irradiation (DNI), while that for fixed Si PV is global tilted irradiation (GTI). The graphs reveal that DNI and electricity generated by CPV are higher than GTI and electricity generated by fixed Si PV, respectively, particularly in the morning and late afternoon. This is the benefit of solar tracking. Compared with the fixed Si PV system, the CPV system generated a higher amount of electricity noticeably during morning and late afternoon, proving its stable power generation during long hours of daytime. This is one feature of power generation systems that incorporate solar tracking, such as CPV. In fact, for the amount of generated electricity per unit area per day, the CPV system generated 2.29 kWh/m^2/day, while the fixed Si PV system generated 0.89 kWh/m^2/day. Consequently, the power generation capacity per unit area of CPV is 2.6 times as high as that of fixed Si PV.

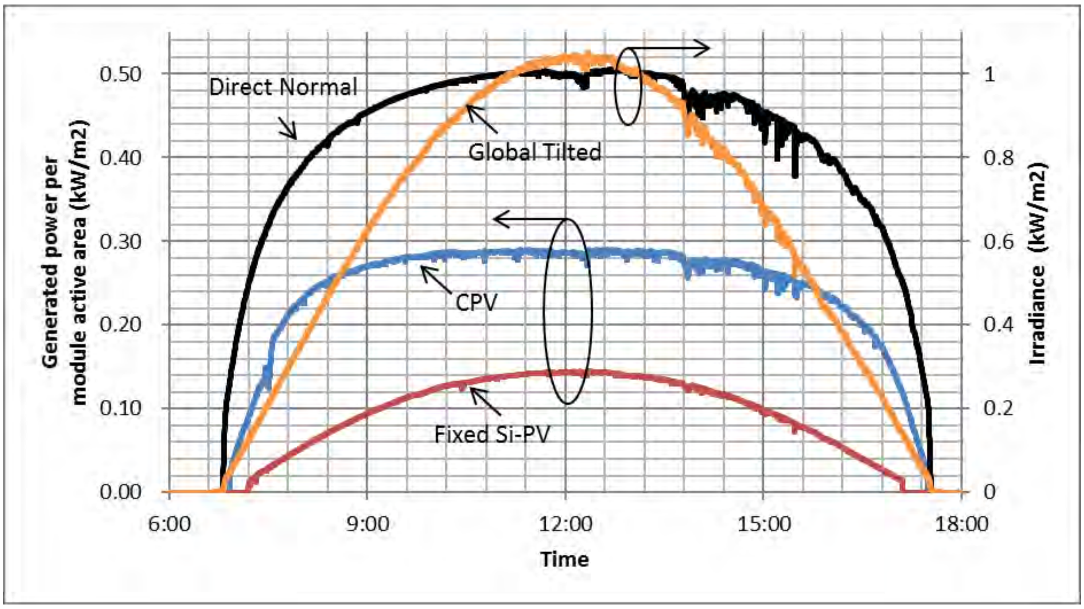


Figure 11 : One Day Trend of Solar Irradiation and Generated Electricity per Unit Area.

Similarly, the amount of generated electricity per nominal output per day is calculated as follows. Power generation data was acquired every 10 seconds. This can be used to determine the hourly average amount of generated electricity. The result is then totalized for one day to obtain the amount of generated electricity per day. By dividing the obtained amount of generated electricity per day by the nominal output of the system, it is possible to determine the amount of generated electricity per nominal output per day. The nominal output figures were 21.9 kW for CPV under CSTC conditions and 10 kW for fixed Si PV under STC conditions. Taking the graphs shown above as an example, for CPV, the amount of generated electricity per nominal output for one day was 7.73 kWh/kW. In contrast, for fixed Si PV, the amount of generated electricity per nominal output for one day was 7.73 kWh/kW. Consequently, on an assumption that the nominal output figures of both systems were identical, the CPV system generated 1.3 times power of the fixed Si PV system.

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This Figure is not publicized as it contains confidential information.

Figure 12 : Generated Electricity per Nominal Output against Cumulative Direct Normal Irradiation

Figure 13 shows plots of seasonal changes in the amount of generated electricity per unit area and that per nominal output.

The changes in the amount of generated electricity per unit area reveal that CPV was generally higher than Si PV throughout periods 1 to 3.

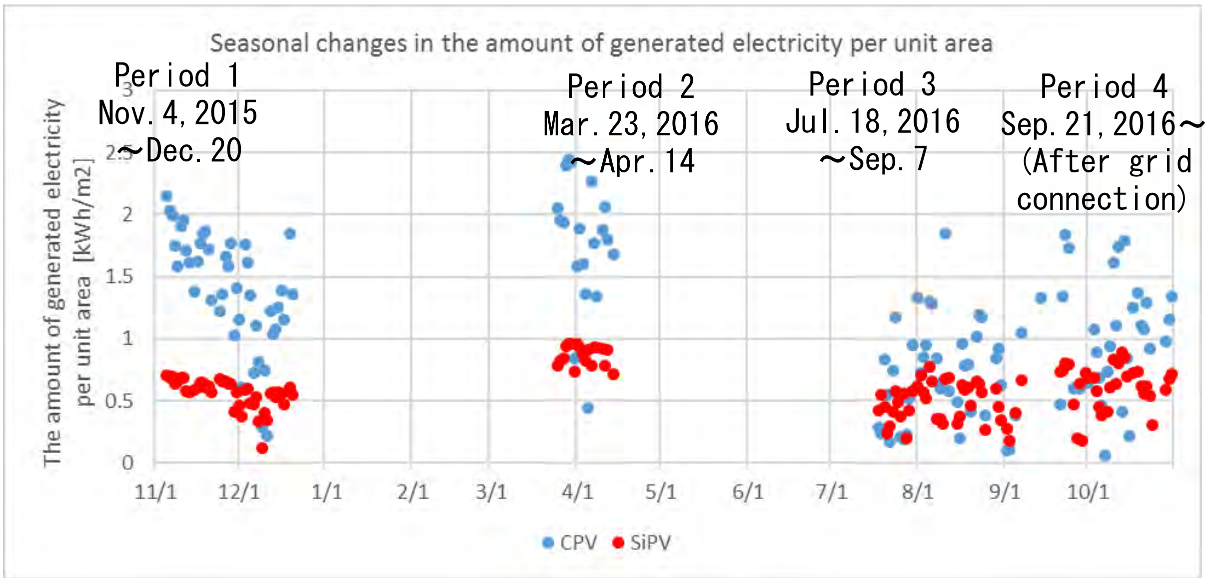

Figure 13 : Seasonal Changes in the Amount of Generated Electricity per Unit Area

Figure 14 plots the amount of generated electricity per nominal output show that CPV performed superiorly to fixed Si PV during the fall to winter and spring seasons, with CPV generating a maximum of 1.3 times power of fixed Si PV. Meanwhile, during the summer period, the amoung of electricity generated by CPV decreased to a level lower than that of fixed Si PV in many days. This was a result of lower direct normal irradiation than global tilted irradiation due to cloudiness in summer in the area of the project site.

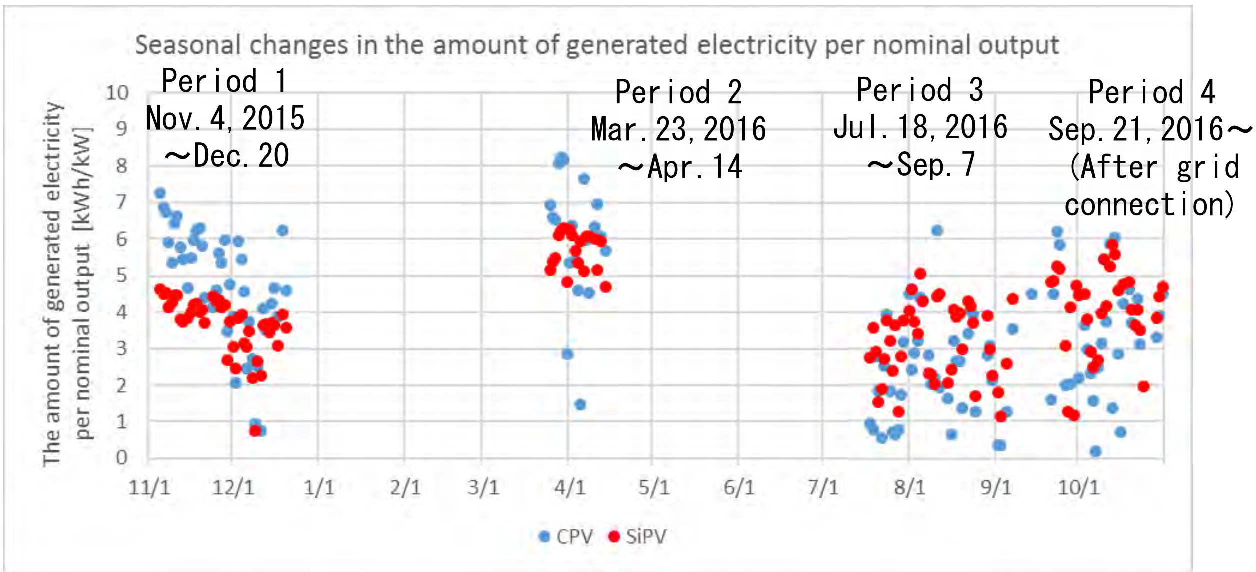

Figure 14 : Seasonal Changes in the Amount of Generated Electricity per Nominal Output

The data acquired from the present demonstration are non-exhaustive, being generated during single-power generation periods, using a diesel generator as a pseudo power grid. As such, we devised a method of estimating the ratio of annual amount of generated electricity between CPV and Si PV, using the data of the actinometer incorporated in the independent power supply system that operated without electricity from power grid.

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This Figure is not publicized as it contains confidential information.

Figure 15 :The Ratio of DNI/GTI (X-axis) ,
The Ratio of Generated Electricity Between CPV and Fixed Si PV(Y-axis)

Note: Definition of nominal output (rating)

The nominal power output values (ratings) of CPV and Si PV are defined using different irradiation conditions. For the analysis of the amount of generated electricity of the two photovoltaic systems, this section uses differently defined reference nominal output values.

CPV rating: at room temperature and direct normal irradiation of 1,000 W/m^2
Si PV rating: at room temperature and global irradiation of 1,000 W/m^2

Global = Direct + Diffuse

Accordingly, indeed in the same environment, Si PV would receive an additional amount owing to scattered sunlight.

3.3. Maintenance and Management

(1) On soiling

To estimate the maintenance and management cost, the demonstration experiment quantified the soiling loss mitigation effect of the inversion mechanism of the new-style solar tracker developed by Sumitomo Electric.

CPV incorporates lenses to concentrate light for power generation. It only uses the direct incident sunlight perpendicular to the photovoltaic receiver surface. In contrast, typical Si PV uses no lens. It uses incident scattered light oblique to the photovoltaic receiver surface, as well as direct sunlight. If the receiver surface is soiled with sand or mud, scattering or reflection of light occurs. Direct normal irradiation is largely affected by soiling of the receiver surface. Consequently, CPV is more affected by soiling than fixed Si PV. Therefore, the mitigation of soiling losses is an extremely important factor for CPV when comparing the amount of generated electricity between CPV and fixed Si PV.

The following photos depict the operation of the actually installed solar tracker. During the daytime, it operates in the same manner as ordinary solar trackers tracking the sun. However, unlike ordinary ones, it is the distinctive feature of the solar tracker to position the CPV receiver surface towards the ground during nighttime non-tracking hours so as to reduce soiling. (Ordinary solar trackers have their receiver surface facing upward.)

The previous in-house demonstration results of Sumitomo Electric showed that sand, the cause of soiling, settled and condensation occurred on receiver glass surfaces in large part during the nighttime. Thus, we verified the soiling mitigation effect of the solar tracker equipped with a nighttime inversion mechanism used in the demonstration.

Tracking

Nighttime stanby

Figure 16 : The Tracker Position (Left: Tracking in Daytime, Right: Standby at Night)

Because the power grid connection work delayed, as explained in the previous section, data was collected during limited periods connecting a generator to the photovoltaic systems. Hence, comparative experiments were conducted as described below.

The construction of the CPV system was completed in early September 2015. Since no power grid was available for about two months from the construction completion, when the system was clean, to early November, the system was left with the photovoltaic receiver surface facing upward. On the last day of this period, the amount of generated electricity before cleaning was compared with that after cleaning to determine the amount of power generation loss due to soiling. The result of the comparison was defined as a "soiling loss from upward-facing standby." Subsequently, in early November, a power generation experiment started using a generator as a simulated power grid. The CPV system operated continuously until late December with the receiver surface tracking the sun during daytime and facing the ground during the nighttime. On the last day of this experiment, the amount of power generation loss was evaluated and defined as a "soiling loss from nighttime inverted standby."

The graphs shown below plot the evaluation results of soiling losses imparted in the two aforementioned patterns. The power generation data were subject to influences such as daily differences in solar irradiation, air temperature, and other factors including trouble. To elucidate soiling losses by removing these influences, we selected data with DNI being at least 400 W/m^2 and made output value conversion using the temperature characteristics of photovoltaic cells to preclude the influences of air temperature. Also removed were losses incurred by aforementioned temporary shutdowns due to strong winds and temporary PCS shutdowns. The resultant corrected power generation data were summed up and defined as the corrected amount of generated electricity. This was then divided by total DNI determined through a similar process to obtain relative output ratio for each day. The graphs represent changes in relative output ratio with reference to that on the first day of each season's experiment, which is 1.

The results showed that the "soiling loss from nighttime inverted standby" was 2.75 times as small as the "soiling loss from upward-facing standby."

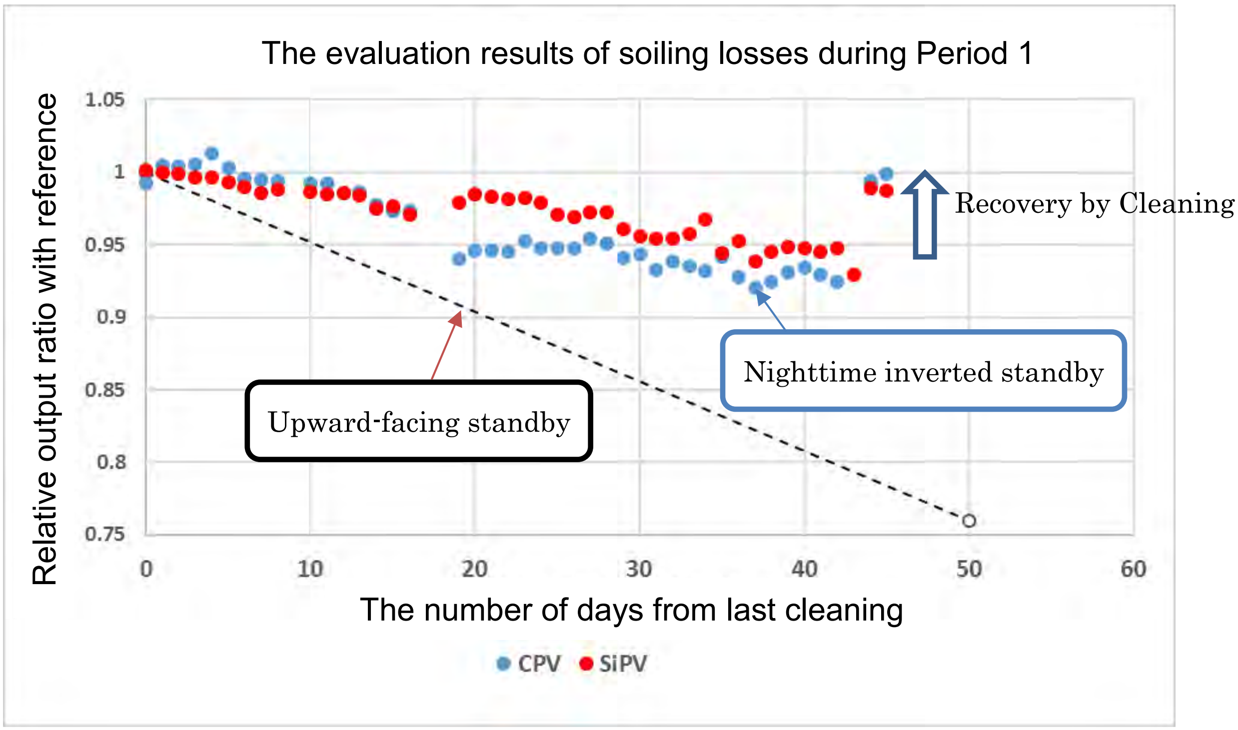

Figure 17 : The Evaluation Results of soiling losses during Period 1

In a strict sense, for comparison purposes, the "soiling loss from upward-facing standby" plotted above should be such that the CPV system track the sun during the daytime and face upward in standby during the nighttime. However, it is highly probable that it does not make much difference with respect to the evaluation results of this project, because the CPV system almost always faced upward tracking the sun during the daytime except for the sunrise and sunset hours.

Figure 17 also plots soiling losses of the fixed Si PV system imparted in the same period as that during which the CPV system was inverted during the nighttime. The soiling losses of the CPV system were at a similar level to those of the fixed Si PV system, as illustrated above. The demonstration proved that even with CPV, which is subject to soiling, it is possible to mitigate soiling losses to a similar level to fixed Si PV by inverting the system during the nighttime.

Additionally, as above, the graphs shown below represent the results of similar processing of data acquired during the summer, Period 3.
The graphs show declining trends similar to Period 1, up to about 20th day from the first. Thereafter, the amount of generated electricity of CPV decreased sharply. This was an influence of rain and strong wind. Wind blew hard on many days between the 30th and 50th days. Under this condition for safety reasons, the CPV system was forced into a horizontal standby position with the receiver surface facing upward. During the standby hours, sand, the cause of soiling settled on the receiver surface. Subsequently, it rained for a long time. This led to the clay-like deposits of a water and sand mixture sticking onto the receiver surface. It is thought that this soiling affected the CPV system and reduced the amount of generated

electricity. (The CPV system was cleaned after the 80th day. Then, the amount of generated electricity recovered to the initial level.)

In contrast, it is inferred that the fixed Si PV system, which was secured at a tilt angle of 20°, was relatively free from the influence of soiling because rain easily flowed down the slope.
The acquired data is highly valuable in terms of mitigating soiling losses of CPV. The demonstration was exceptionally significant identifying the need to develop an optimal solar tracking control according to the weather conditions at the site, such as devising a retracting position to withstand strong winds and forecasting rain, along with inverting the position during the nighttime.

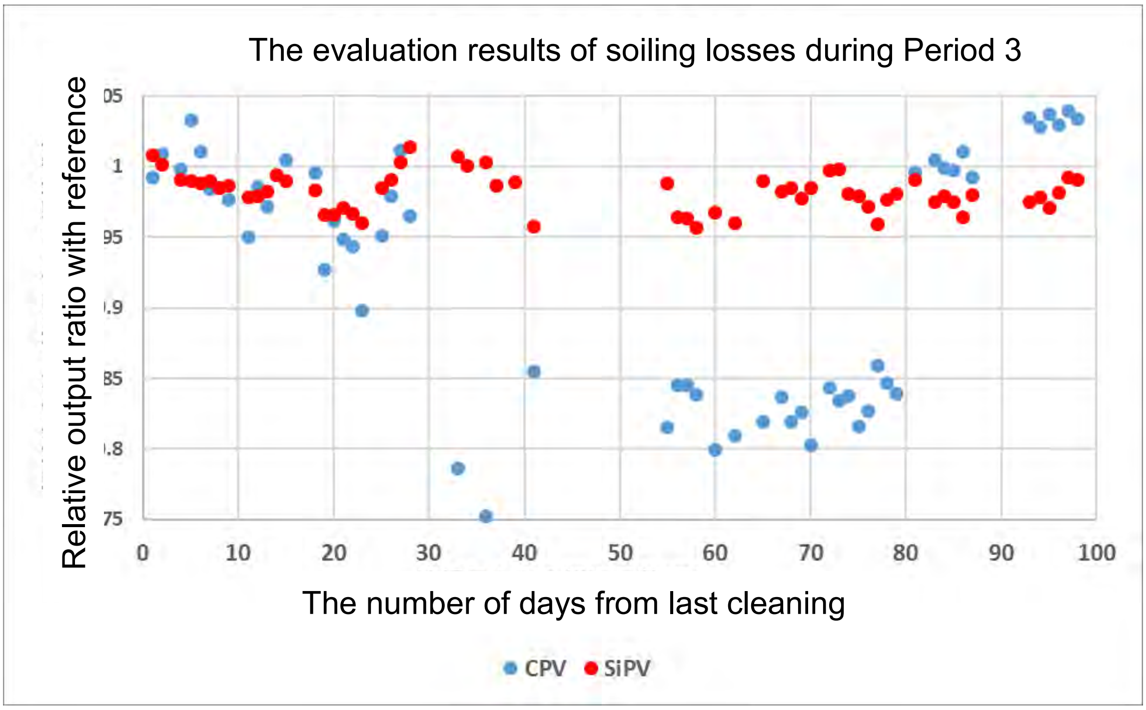

Figure 18 : The Evaluation Results of Soiling Losses During Period 3

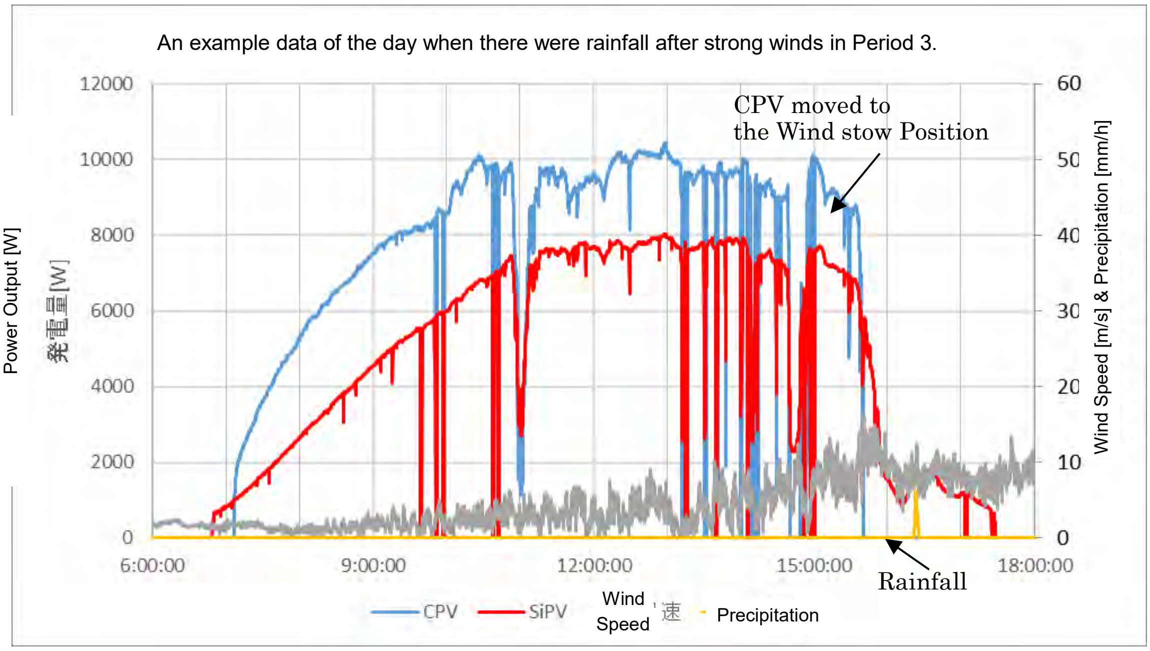

Figure 19 : An Example Data of the Day Having Rainfall after Strong Winds in Period 3

The demonstration also included an assessment of suitable CPV system cleaning methods for the site. The results are shown below.

	Cleaning Effect	Ease of Work	Description
① Cleaning brush for elevated components	△	×	
② Jet cleaner	×	○	
③ Elevated platform + hand cloth	○	△	Worker on an elevated platform wipes each panel clean by hand. → High cleaning effects, yet time consuming
④ Elevated platform + Jet air	×	○	Strong blast of air from a blower Not much effective against clay-like deposits of soil
⑤ Elevated platform + hand wiper	○	○	

○: good △: fair ×: poor

Table 4 : The Results of CPV Module Cleaning Method Evaluation

First, we provided cleaning brushes for elevated components (①) and jet cleaners (②), neither of which were effective in achieving expected cleaning effects. Next, we explored other techniques. More specifically, taking note that an elevated platform plus the inversion mechanism incorporated in the demonstration would enable workers to access the photovoltaic receiver surface, we additionally compared the cleaning effects and ease of work of several cleaning techniques that could be adopted by workers (③, ④, and ⑤ in the chart above). As a result, using an elevated platform to access the receiver surface and cleaning it with a hand wiper (⑤) , as with the windows of a high-rise building, was highly effective for cleaning and ensured ease of work.

The CPV system equipped with an inversion mechanism used in the demonstration turned out to be effective also with respect to system cleaning carried out as part of O&M. The inversion mechanism proved itself to be significantly effective for the introduction of CPV systems to the project site.

Figure 20 : The Picture of Workers carrying out cleaning on site

(2) Transfer of control of O&M to local staff

The maintenance menu used in the demonstration is shown below. Since the demonstration started, locally hired workers have been conducting on-site maintenance work. The following operation requires two workers.

Future tasks include working out staffing and maintenance items for large CPV systems.

Table 5 : The Maintenance Menu (Above: Periodical Maintenance, Below: Cleaning)

This Table is not publicized as it contains confidential information.

4. Project Achievements

4.1. Development of Next Project

Building a good relationship with the local authorities is one essential key to a successful infrastructure project. In addition, in consideration of the need to meet high local content requirements, it is also imperative to find and collaborate with reliable local partners.
The governmental partner for the present project is MASEN, the agency in charge of the solar power policy and planning/running of major tenders in Morocco. This project is our first step towards nurturing a direct relationship with MASEN. The project's success is critically vital for our future CPV business development in Morocco.

MASEN plays a leading role in introducing renewable energy to Morocco. In this project, we presented MASEN with briefings on CPV technology and the demonstration experiment process with the aim of proving the technology. More specifically, we presented the results of the amounts of electricity generated by CPV and Si PV and explained that the CPV system had shown an advantage over the Si PV system under high irradiation conditions and could be inverted during the nighttime to avoid soiling. One concern raised by MASEN was power generation loss that CPV would suffer due, for example, to inadequate tracking accuracy. The agency understood that the system had generated the planned amount of electricity as proven through the demonstration. Regarding O&M, MASEN was concerned most about power generation losses caused by sand soiling commonly observed in desert areas. We explained the agency that the demonstration had proven the effectiveness of inverting the system during the nighttime for a reduced cleaning frequency and that cleaning experiments were useful for optimizing cleaning techniques to sufficiently recover the capacity to generate electricity. Regarding cleaning, MASEN understood that, with small systems, the manual cleaning technique used in the demonstration would be advantageous in terms of cleaning quality, cost, and local employment. Moreover, we explained Sumitomo Electric's plans for raising local content, such as development of a CPV assembly plant in Morocco and procurement of solar trackers from local manufacturers. The agency recognized that CPV would contribute not only to the introduction of solar power to Morocco, but also to the industrial sector in the country.

Within the period of the demonstration project, these explanations helped MASEN see CPV business development potential in Morocco. As a consequence, in May 2016, Sumitomo Electric and MASEN signed a contract to jointly operate and demonstrate a 1 MW CPV plant. The construction of the plant was completed on November 10, 2016 incidentally during the period of COP 22. The completion ceremony was attended by Mr. Mustapha Bakkoury, President of MASEN, Mr. Hicham Bouzekri, CEO of MAScIR, and other Moroccan government officials, along with Mr. Tsuneo Kurokawa, Ambassador Extraordinary and Plenipotentiary of Japan to the Kingdom of Morocco and Mr. Hitoshi Tojima, Chief Representative of JICA Morocco Office, among other people. At the ceremony, we highlighted CPV technology and business development initiatives. Furthermore, on November 8, 2016 at COP 22, the Japanese pavilion and MASEN jointly presented information about the present project and the 1 MW plant. Making the best use of the 1 MW pilot power generation plant as well as the engineering demonstration of the present project, we intend to establish collaborative relationships with local research institutes, including MAScIR, and local suppliers, aiming at future mass production of CPV in Morocco. At the same time, we will establish operation and maintenance techniques for stable CPV plant operation to prove the advantageous performance of the CPV plant as a power plant.

Morocco plans to introduce 2,000 MW solar energy by 2020. Price is one important criterion that MASEN uses in its plan to assess engineering. CPV is anticipated to create a solar industry and jobs in Morocco if its cost reduces to a competitive level competing against Si PV. MASEN therefore is interested in the CPV technology. Thus, Sumitomo Electric aims to plan a next project, while explaining and proposing MASEN about cost reduction and a roadmap for factory development in Morocco, and providing briefings about demonstration results of the present project and the 1 MW plant.

News Release

住友電工

November 11, 2016

Sumitomo Electric Industries, Ltd

Sumitomo Electric Starts Operation of Concentrator Photovoltaic Power Generation Pilot Plant

Sumitomo Electric Industries, Ltd. has completed the construction of a 1 MW concentrator photovoltaic (CPV) power generation plant in the Kingdom of Morocco, and held a completion ceremony on November 10, 2016.

On November 10 (local time), Sumitomo Electric held a ceremony to celebrate the completion of its megawatt-class CPV power generation plant in Ouarzazate City, the Kingdom of Morocco. The company had been working on the construction of the project facility since June based on the contract made this May with the Moroccan Agency for Sustainable Energy (MASEN).

The ceremony was attended by over 100 representatives from the two countries, including Mr. Mustapha Bakkoury, President of MASEN, Mr. Tsuneo Kurokawa, Ambassador Extraordinary and Plenipotentiary of Japan to the Kingdom of Morocco, and other government officials.

At the completion ceremony

PV power generation plant

Encouraged by the successful commencement of this project, Sumitomo Electric will promote its CPV business not only in Morocco but also in other countries, in the Middle East and the rest of the world, that have high solar radiation.

Project Outline

Facility	CPV 1MW
Location	Ouarzazate City, the Kingdom of Morocco In the site of the MASEN Solar Energy Power Generation Project
Operation	Launched in November 2016
Project duration	Five years from the conclusion of the agreement (until May 2021)

[Reference]

Press release on May 11, 2016

Sumitomo Electric Made the Contract with the Moroccan Agency for Sustainable Energy Regarding Operation of Concentrator Photovoltaic Power Generation Pilot Plant

http://global-sei.com/company/press/2016/05/prs034.html

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SUMITOMO ELECTRIC GROUP

Figure 21 : Sumitomo Electric news release dated November 11, 2016

4.2 Finding Local Enterprises and Transfer of Control

To implement the present project in Morocco, looking for local firms and transferring control to them was essential in light of local employment creation, cost (tariff and transportation) and time period considerations. For the present project, we entrusted local EPC businesses to localize the basic design drawn up by Sumitomo Electric, to construct, and to procure some parts and materials. Moreover, we have optimized O&M techniques for post-construction O&M work and transferred control thereof to local companies. More specifically, the EPC contractor was in charge of the tracker foundation, tracker structure and electrical designing confirmation for local code. In addition, the general equipment, such as Si PV and Fence, was procured from local vendor. The Ouarzazate locally hired workers conducted the construction at site under the supervision of SEI.

For the future, we plan to take charge of key engineering and design specific to CPV in Japan and transfer control to local firms regarding the manufacture, procurement, construction, and O&M.

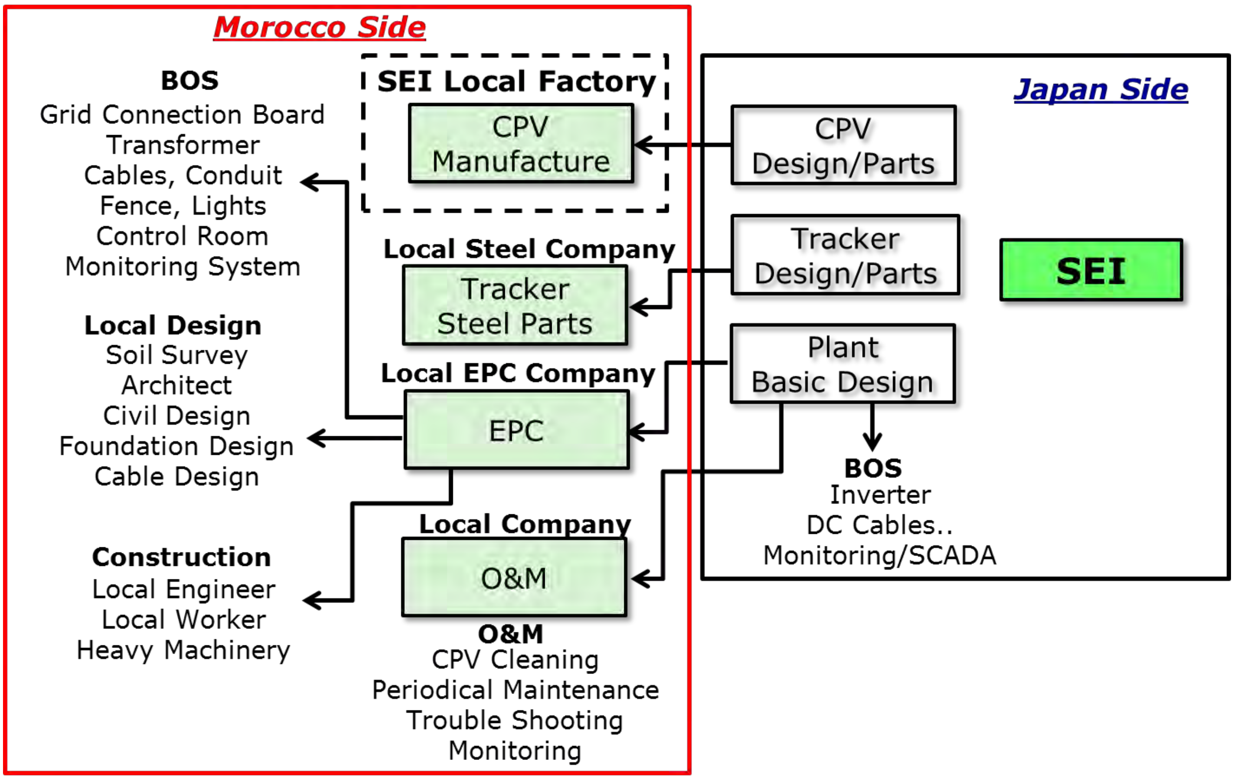

Figure 22 : Concept of CPV system localization

Specifically, regarding the assembly of CPV modules, we assume that a production plant be set up locally to supply in Morocco, as shown above, and also to export products to high DNI regions suitable for CPV throughout the world.

5. Future Project Development

5.1 Business Plan

Morocco has announced guidelines for the introduction of solar energy to reach 2,000 MW by 2020 and 4,560 MW by 2030. Major relevant measures in place or planned are tenders for the IPP business license run by MASEN and EPC tenders run by ONEE. In addition, development of institutional design is under way for power generation by private sectors and electricity selling businesses. For example, MASEN is currently working on a tender process for the solar energy business license in the first phase (approx. 400 MW) of the Noor Midelt project. Moreover, a plan for a second phase (approx. 400 MW) has been drawn up. Also, ONEE is working on an EPC tender process for photovoltaic systems for the Noor Tafilalet project (120 MW). Following this, the Noor Atlas project (200 MW) and the Noor Argana project (200–225 MW) have been planned.

Sumitomo Electric intends to work on business development in Morocco, on the basis of operation and demonstration of the megawatt-class power plant mentioned in 4.1. Currently conceivable options include selling systems and devices to MASEN and ONEE projects and private companies, participation in MASEN projects (as an IPP business entity), and business generating or selling electricity. We will explore the form of business participation in a timely fashion according to the development situation of CPV mass-production technology, the legal system preparation situation in Morocco, and project creation.

Another plan under consideration is setting up a CPV module assembly plant in Morocco. We would like to contribute to building a society running on sustainable electrical energy and to creating investment and job opportunities in Morocco. In consultation with the Ministry of Industry, Commerce and Handicraft of Morocco, which is promoting foreign investment, we intend to gain assistance from the country, such as tax exemptions.

Furthermore, we plan to expand our business from Morocco to African and Middle Eastern countries (especially, French-speaking African nations given Morocco's close relationships with them) and to other high solar irradiation regions throughout the world.

5.2 Possibility of collaboration with ODA projects

The Country Assistance Policy for the Kingdom of Morocco published in May 2012 by the Ministry of Foreign Affairs of Japan sets out development and provision of industrial infrastructure and capacity development with the aim of assisting sustainable economic growth in Morocco. Especially, the policy emphasizes on assistance for sustainable development of the country through utilization of Japan's expertise in solar energy, environmental policy and resource management. The CPV project of Sumitomo Electric is thought to have enough potential to be a comprehensive solution for such agendas. As an exit strategy to take after the present project, Sumitomo Electric intends to explore the possibility of suggesting MASEN to draw up ODA funded projects, and, we believe, the fact that we managed to sign the contract of joint operation and demonstration of the 1MW CPV plant with MASEN shall lead us to such futher development.

5.3 Action Plan for Solving Challenges

The chart below summarizes currently recognized challenges or tasks to be addressed after the present project and an action plan drawn up to solve or achieve them.

Table 6 : Action Plan

No.	Category	Challenge/Task	Action for solution/achievement	Expected timing
1	Cost	Reduce the O&M cost	• Continue testing the anti-soiling function of the solar tracker. Examine its effect in reducing year-round cleaning and other O&M cost.	late 2017
2	Quality	Evaluate stability in power generation	• Continue the evaluation of power generation performance at a stable quality level as a power source after connecting to the power grid. • Continue data analysis and provide feedback information for improved power generation performance.	late 2017
3	Business development	Analyze business participation forms followed in Morocco.	• Understand the local legal system. • Explore candidate projects.	late 2017
4	Business development	Participate in MASEN projects	• Ensure stable CPV plant operation and establish maintenance techniques. • Demonstrate CPV's advantages for use in power plants. • Work out joint projects with MASEN.	early 2018
5	Business development	Set up a local CPV module assembly plant in Morocco.	• Consult the Ministry of Industry, Commerce and Handicraft of Morocco to look for the possibility of aid such as tax exemptions from the national government. • Nourish collaborative relationships with local research institutes including MAScIR and local suppliers.	late 2018
6	Business development	Explore the possibility of ideas that can receive financial assistance as an ODA funded project	• Continue talks with the Moroccan government, including MASEN.	2019