HONG KONG'S LARGEST SOLAR FARM AT SIU HO WAN SEWAGE TREATMENT WORKS

ABSTRACT

The Drainages Services Department (DSD) commissioned the Hong Kong's largest solar farm in Siu Ho Wan Sewage Treatment Works (SHWSTW) in December 2016, which was a new milestone in adoption of renewable energy technology in Hong Kong. Comprising over 4,200 no. polycrystalline photovoltaic (PV) panels, the solar farm in SHWSTW has an installed generation capacity of over 1,100 kilo-watt (kW). The annual electricity generation is estimated at 1,100,000 kilo-watt-hours (kWh), which is equivalent to 770 tonnes reduction of carbon dioxide emission per year.

The electricity generated by the solar farm is connected to the internal power distribution network of SHWSTW for supplying electricity to its various equipment and systems, which accounts for approximately a quarter of annual electricity consumption of the plant.

There are three major innovative designs in the solar farm. Firstly, all PV panels were fixed on pre-fabricated concrete blocks, which provide flexibility of relocating the whole or part of the system for future development of SHWSTW. Secondly, DSD introduced an intelligent Direct-Current (DC) combiner box for part of the solar farm as a pilot trial, which allows the plant operators to effectively locate any faulty PV panels in the solar farm occupying a footprint of 11,000 m^2. Lastly, provisioning of the Solar Farm Monitoring Room makes available a centralized monitoring system for the operating staff and space for displaying panels and multimedia information for visitors to understand more on renewable energy technologies.

In the 21st Conference of the Parties of the United Nations Framework Convention on Climate Change held in December 2015, the Paris Agreement was adopted by consensus, aiming at "strengthening the global responses to the threat of climate change and the ability of countries to deal with the impacts of climate change" [1]. In the 2016 Policy Address of the Hong Kong Special Administrative Region (HKSAR) Government, it also stated that "the Government will take forward mitigation measures proactively" [2]. This was further strengthened in the 2017 Policy Address that "the Government will study how to further promote energy saving and renewable energy generation" [3]. To combat climate change, DSD will keep on collaborating with relevant stakeholders and promoting renewable energy and energy conservation by incorporating sustainable development elements into its facilities. Different forms of renewable energy including solar energy and biogas are currently supplying a total of 32 million kWh of energy for DSD's facilities, constituting about 10% of departmental total annual energy consumption. DSD will continue to enhance the total energy management strategy for its facilities and extend the application of renewable energy, with a view to developing Hong Kong as a low-carbon and livable city.

Keywords: Hong Kong's Largest Solar Farm, Renewable Energy, Sustainable Development, Combating Climate Change, Innovative Design

PROJECT BACKGROUND

DSD's vision is to provide world-class wastewater and stormwater drainage services enabling sustainable development of Hong Kong. Operating over 300 sewage facilities across Hong Kong territory, DSD is the fourth largest electricity consumer amongst various departments in the HKSAR Government. In order to enable sustainable development of Hong Kong, as well as to combat climate change, DSD has deployed ample resources in adopting renewable energy element for its new and existing sewage facilities. The Hong Kong's largest solar farm in SHWSTW is one of the major renewable projects in recent years.

In mid-2014, Electrical and Mechanical Projects Division of DSD (the Division) initiated the design of the solar farm, with tenders for the works being invited in November 2014. This works contract was managed under the arrangement of New Engineering Contract (NEC), Engineering and Construction (ECC) Option A, which was the first contract of its kind in DSD. Having assessed various submissions from tenderers, the Division awarded the works contract to CLP Engineering Limited in February 2015. A summary of the contract details and project development programme is shown in Tables 1 and 2 below:-

Table 1 Contract Details

Contract No.	DE/2014/03
Contract Form	NEC ECC Option A
Contractor	CLP Engineering Limited

Table 2 Project Development Programme

Detailed Design Stage	July 2014 – October 2014
Tendering Stage	November 2014 – February 2015
Contract Commencement	February 2015
Preparation Works	February 2015 – May 2015
Site Work Commencement	June 2015
Completion of 1st Phase (Area A, 174.72 kW)	December 2015
Whole System Commissioning	December 2016

Figure 1 below shows the layout plan, including the locations of Solar Farm Areas A, B and C, as well as some ancillary equipment and key buildings inside the plant.

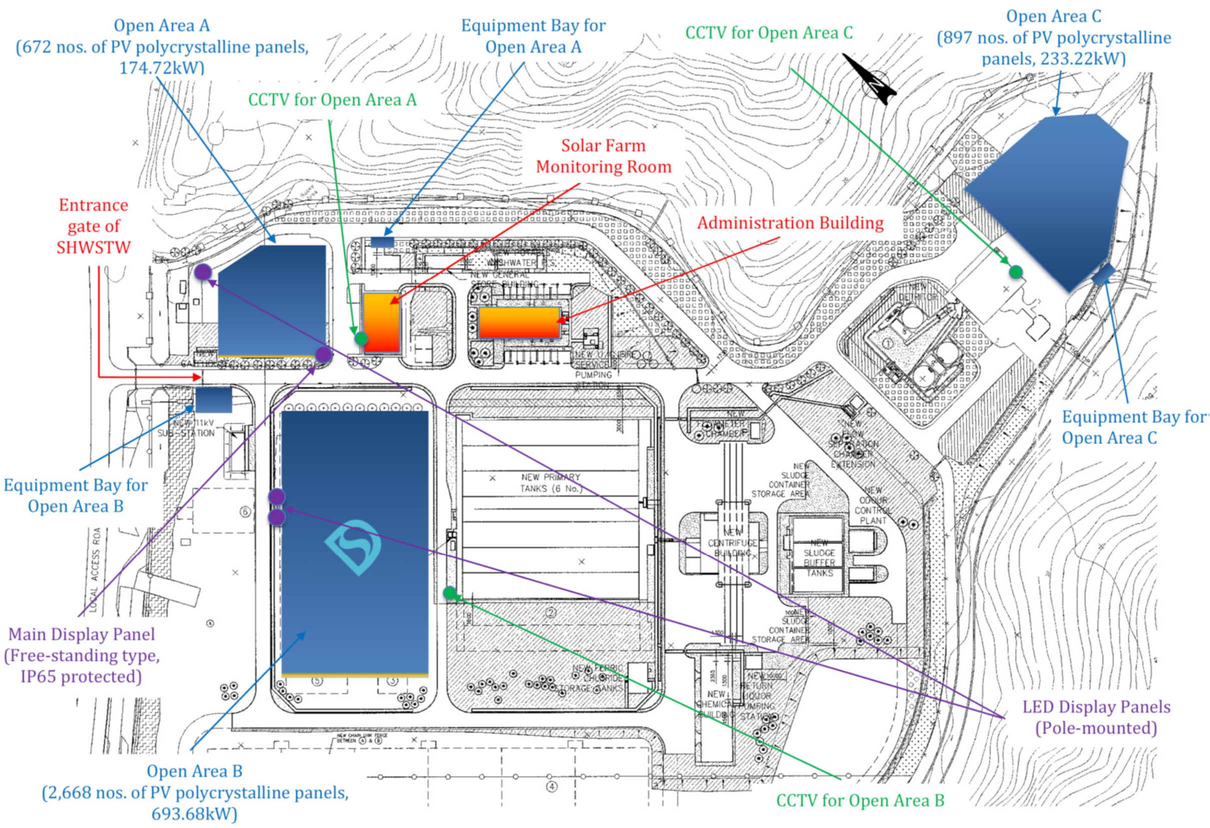

Fig. 1 Layout Plan of Siu Ho Wan Sewage Treatment Works

Having completed the installation of the whole solar farm in November 2016, an aerial photo of the SHWSTW was taken as shown in Figure 2 below:-

Fig. 2 Aerial Photo of Siu Ho Wan Sewage Treatment Works

DESIGN CONSIDERATIONS

Project Objectives

DSD operates about 70 sewage treatment plants with a daily sewage treatment capacity of 2.74 million cubic meters, equivalent to the capacity of 1,096 standard swimming pools. A large amount of energy is required for the daily operation. To align with its vision, DSD strives to strengthen the energy management of plant facilities and looks for opportunities to adopt renewable energy element in its sewage treatment plants.

Solar Resources in Hong Kong

In order to have a better understanding on the solar resources available across Hong Kong territory, a map showing the Global Horizontal Irradiation across South and Southeast Asia obtained from the SolarGIS GeoModel Solar [4] was studied.

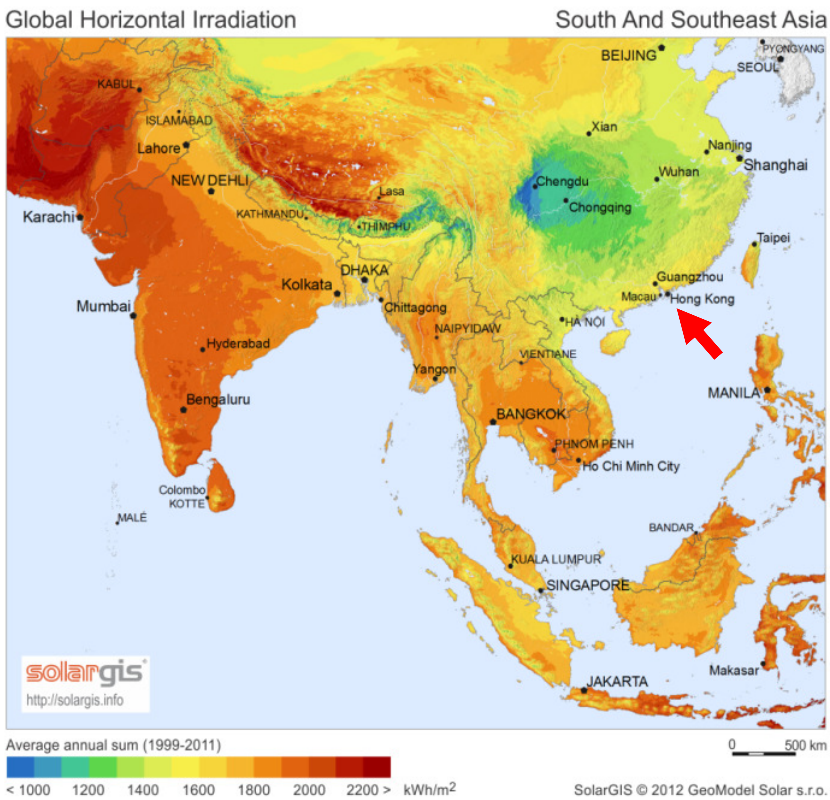

Fig. 3 Map of Global Horizontal Irradiation in South and Southeast Asia

The map in Figure 3 above shows that the average annual sum from 1999 – 2011 in Hong Kong was about 1,400 – 1,600 kWh/m^2, which was found to be at a moderate level on a world-wide scale. By taking into account various factors including the efficiency of PV panels, losses in electrical systems, shading effect etc., with the assumption of 10% irradiation to be converted by the solar system into electrical energy, the annual estimated electricity generation by the solar farm would be about 140 – 160 kWh/m^2. If space could be made available inside a STW, this would bring benefits to DSD for making use such solar energy generated, as a kind of green energy, to reduce the plant's electricity consumption.

Site Selection

With the above objectives, a site search exercise for adoption of solar energy in sewage treatment plants was conducted. Some key factors, including available area with future upgrading considerations, shading effect and visual impact, access for operation and maintenance etc., were considered in selecting suitable STW for installation of the PV system. SHWSTW was finally considered as a suitable location for the following reasons:-

1. Available area with future upgrading considerations
   As one of the key infrastructures in North Lantau Island, sufficient land resources have been reserved in SHWSTW for future possible plant capacity and treatment process upgrading so as to cope with the planned long-term development in the region. As there was room for enhancement for utilization of some plant areas in the meantime, it provided opportunities for DSD to best utilize the land space by installing the PV systems. This initiative would not only provide green energy to the E&M equipment inside the plant, but also show the commitment of the Government by taking the lead to adopt renewable energy and combat climate change. This would also arouse public awareness on utilization of renewable energy, echoing the objectives of this project.

   The design of the solar farm also allowed flexibility so that the solar farm can be relocated for future development whenever necessary.

2. Shading effect and visual impact
   Locating in Cheung Tung Road, SHWSTW is situated in rural area without high-rise buildings and residential areas nearby. Shading effect by obstacles was therefore minimized, which led to high system efficiency during operation stage. Also, visual impact to the sensitive receivers could also be minimized.

3. Access for operation and maintenance
   In order to avoid any possible damages of the water proofing layer on the roof of existing buildings, as well as to reduce the complexity of system installation by providing convenient access, the solar farm installation was designed on ground level. Sufficient space between rows of PV panels was considered important from design and operation point of view. This would not only allow sufficient space for operation and maintenance, but also prevent the self-shading effect by PV panels, especially during the early morning or late afternoon with low sunshine pitch.

Types of Solar Panels

There are currently three major types of PV panels, namely monocrystalline, polycrystalline and amorphous thin-film, in the market. Pros and cons of these PV panels are listed below.

Table 3 Pros and Cons of Different Types of PV Panels

	Pros	Cons
Monocrystalline	● Highest efficiency ● Smallest footprint	● Highest cost
Polycrystalline	● Moderate efficiency and footprint	● Relative high cost
Amorphous thin-film	● Lower cost ● Good performance in weak light environment	● Lowest efficiency ● Largest footprint

Having considered the above factors, DSD decided to set the required installed generation capacity requirement in the tender document, and allow the tenderers to adopt either monocrystalline or polycrystalline PV panels as the major portion of the solar farm. Although the cost of monocrystalline PV panels is higher, these panels have a higher efficiency and thus require smaller footprint and less panels to meet the installed generation capacity requirement. On the other hand, while the cost of polycrystalline PV panels is lower, these panels have a lower efficiency and thus require larger footprint and more panels to meet the installed generation capacity requirement. Subsequent to the tendering exercise, the Contractor proposed to use polycrystalline PV panels for the solar farm during equipment submission stage.

Fig. 4 Polycrystalline PV Panels

Grid Connection Arrangement

Since the power output varies with the environment, e.g. sunlight and radiation intensity, weather etc., the solar farm had to be either connected to a battery system for storage of electrical energy so generated, or directly connected to the internal power distribution network for the equipment.

In view of the scale of the solar farm, the use of battery storage system was not preferred as it required significant amount of batteries, and disposal of which upon end of service would cause environmental problems. Such decision aligned with the "Technical Guidelines on Grid Connection of Renewable Energy Power Systems, 2016 Edition" published by the Electrical and Mechanical Services Department [5].

Instead of using battery storage system, the electrical network of solar farm was connected directly to the power company's supply grid which provides continuous electricity supply for the E&M equipment in the plant.

The brief procedures of Grid Connection with the power company are:

1. the Contractor designed the solar system and submitted the finalized grid connection details with the power company, who provided technical advice during the process;
2. the solar system was installed on site;
3. the power company conducted site tests upon completion of installation; and
4. the solar farm electricity generation system was connected with the power company's supply grid for parallel operation.

Flexible Relocation of Solar Farm

SHWSTW is currently serving North Lantau Island, including areas in Tung Chung, Hong Kong International Airport, Discovery Bay and Penny's Bay, with a population of around 200,000. While the HKSAR Government has been planning to further develop these areas in the near future, being one of the major infrastructures within the area, we foresaw that expansion, upgrading or even relocation of SHWSTW might be required to suit the future development.

Fig. 5 Concrete Support for PV Panels

In order to accommodate the possible future development, instead of using traditional metallic frame supports, DSD introduced pre-fabricated concrete supports for installation of PV panels. All PV panels were installed on readily movable concrete supports, which provided flexibility in relocating the PV panels to other locations during future expansion or redevelopment of SHWSTW without demolition works and construction waste. Each concrete support weighs about 1 tonne without mechanical anchorage on the blinding layer underneath so that the whole system can sustain the wind load, even during the typhoon seasons.

Intelligent Detection System

The footprint of the whole solar farm in Areas A, B and C occupied over 11,000 m^2. It would be challenging for the plant operators to operate and maintain over 4,200 no. PV panels, especially to identify the location of the faulty panels for rectification or replacement works. As a pilot trial, amongst the 12 no. DC combiner boxes in the solar farm, DSD introduced one intelligent DC combiner box to serve part of the solar farm to detect and identify any malfunctioned PV panel(s) speedily and effectively. Upon satisfactory performance, the system would be extended to the remaining part of the solar farm.

Fig. 6 Intelligent DC Combiner Box

SOLAR FARM

Occupying an area of over 11,000 m^2, the solar farm in SHWSTW was installed in three areas, namely Area A, Area B and Area C.

Fig. 7 Aerial Photo of Area B

 

Fig. 8 and 9 Aerial Photos of Area A (left) and Area C (right)

The solar farm, comprising 4,237 no. polycrystalline PV panels, had an installed generation capacity of 1,100 kW. The overall equipment and installation cost of the whole solar farm was HK$27M.

Table 4 Parameters of Solar Farm in Areas A, B and C

Parameters	Area A	Area B	Area C	Total
Approx. Area	1,650 m^2	7,200 m^2	2,150 m^2	11,000 m^2
No. of Inverters	2	7	3	12
No. of PV Panels	672	2,668	897	4,237
Installed Generation Capacity	174.72 kW	693.68 kW	233.22 kW	1,101.62 kW

With the grid connection, the electricity generated by the solar farm would be used for supplying power to various equipment and systems in SHWSTW, including ultraviolet (UV) disinfection system for treated effluent, influent screening, sludge dewatering facilities and the E&M equipment inside Workshop Building and Administration Building via the internal power distribution network.

PV PANELS

The technical specifications of the polycrystalline PV panels adopted in the solar farm are summarized in Table 5 below.

Table 5 Technical Specifications of PV Panels

Parameters	Polycrystalline
Place of Manufacture	China
Panel Power	260 W
Dimensions	1,658mm x 992 mm x 6mm
Panel Weight	23.5 kg
Colour	Dark Blue
No. of Cells per Panel	60
Module Efficiency	15.8%
Total No. in Solar Farm	4,237
Inclination	22^o towards South

SYSTEM CONFIGURATIONS

Table 6 below briefly describes the system configurations, including no. of PV panels forming a string, no. of strings for one DC combiner box, and no. of Direct Current – Alternating Current (DC-AC) inverters used in the three solar farm areas.

Table 6 System Configurations of Solar Farm

Solar Farm Area	No. of PV Panels	No. of Strings to DC-AC Inverter	No. of PV Panels for each String	No. of PV Panels for Solar Farm Area
A	24	14	336	672
	24	14	336	
B	23	16	368	2,668
	23	16	368	
	23	16	368	
	23	17	391	
	23	17	391	
	23	17	391	
	23	17	391	
C	23	13	299	897
	23	13	299	
	23	13	299	
Total				4,237

String of PV Panels

A string of PV panel was formed by connecting 23 – 24 no. polycrystalline PV panels under in-series arrangement. The number of PV panels was designed to suit the optimum operating range of the DC-AC inverters.

The operating DC voltage and current for one string of PV panels were designed in accordance with the international standards to reach up to over 700 V_{DC} and 140 A respectively.

DC Combiner Boxes

After forming strings of PV panels, these strings were connected in-parallel and fed into the DC combiner box. The function of the DC combiner box was to combine all current and voltage generated from various strings of PV panels as a single point feeder for connection to the DC-AC inverter for transforming the DC voltage and current generated by the PV panels into AC mode before connecting to the existing LV switchboard of the plant and the grid.

As mentioned in the preceding section, there were totally 12 no. DC combiner boxes in the solar farm, of which one of them was intelligent type as a pilot installation.

Fig. 10 DC Combiner Boxes

Fig. 11 DC-AC Inverters

DC-AC Inverters

After receiving the DC voltage and current from the DC combiner boxes, the DC-AC inverters convert the DC input to AC output, which would then be fed to the existing LV switchboard inside the plant for grid connection and supplying electricity to the E&M facilities. The rectifier loss of the inverter is approximately 5%. Technical specification of the DC-AC inverters used in the solar farm is summarized in Table 7.

Table 7 Specification of DC-AC Inverters

Parameters	Value
Max. DC Input Voltage	900 V_{DC}
Max. DC Input Power	110 kW
Max. DC Input Current	250 A
Nominal AC Output Power	100 kW
Max. AC Output Current	158A
Max. Efficiency	96.5%

A typical connection of the PV panels in Area C is shown in Figure 12 below.

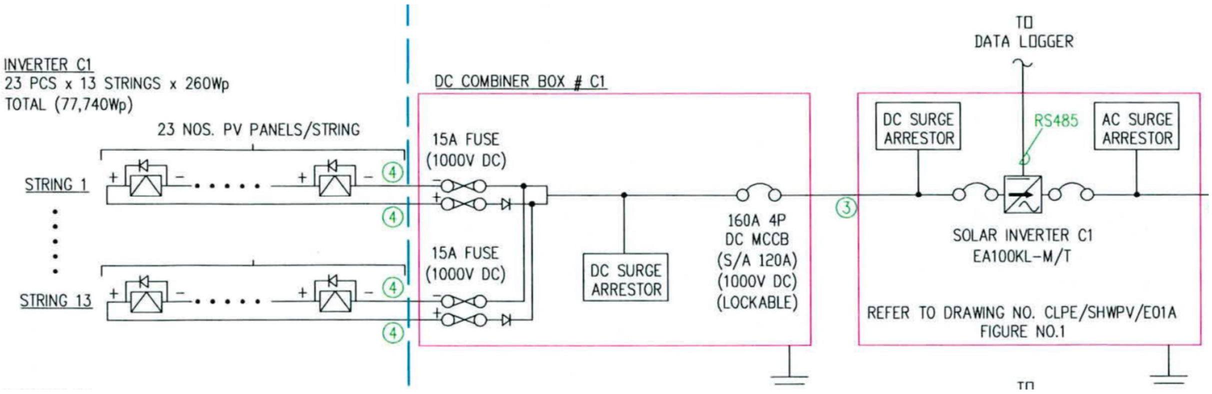

Fig. 12 Connection of Strings of PV Panels to DC Combiner Box and Inverter

SOLAR FARM MONITORING ROOM

The solar farm monitoring room provides a real-time centralized monitoring system to facilitate daily operation and provide energy generation data of the solar farm. The closed-circuit television (CCTV) system enables centralized monitoring on the operating environment in Areas A, B and C. As an innovative and convenient measure, the plant operators can use the apps installed in portable devices to pan, tilt and zoom the three CCTV cameras for the three areas to obtain real-time images of the system, instead of using the dedicated control panel.

Fig. 13 CCTV system

The Solar Farm Monitoring Room also receives signals from the intelligent DC combiner box. Operators can therefore check the signals of the PV panels, which are connected to this intelligent DC combiner box, and take necessary actions for malfunctioning panel(s).

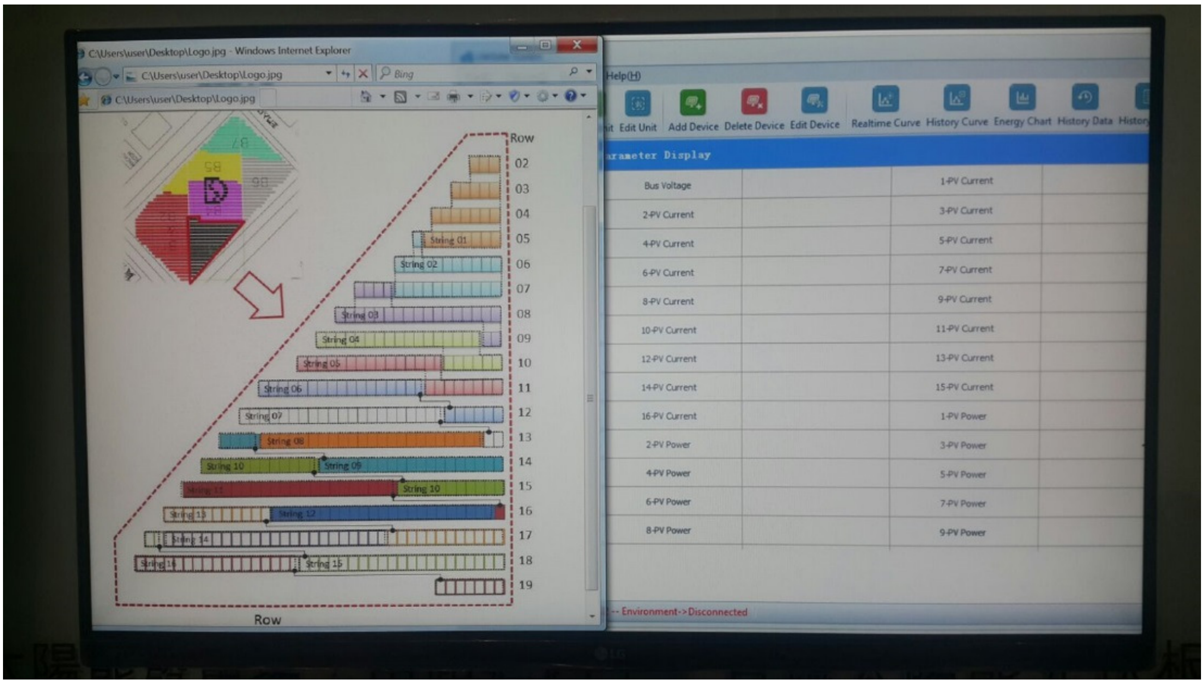

Fig. 14 Interface and Signals of Intelligent DC Combiner Box

Other than the CCTV system and the signal from the intelligent DC combiner box, the Solar Farm Monitoring Room also contains educational materials on different forms of renewable energy (e.g. biogas, solar energy etc.) used by DSD and serves as an information hub for visitors.

Fig. 15 and 16 Solar Farm Monitoring Room with Centralized Monitoring System, Panels and Multimedia Information of Renewable Energy

OPERATOIN DATA FOR TRIAL RUN OF AREA A

E&MP Division of DSD started the solar farm installation works on site in June 2015, with the first phase, i.e. Area A, completed in December 2015. The system in Area A at 174.72 kW underwent a 1-year pre-commissioning trial after installation, and the recorded electricity generation from December 2015 to November 2016 is presented in Figure 17 and Table 8 below.

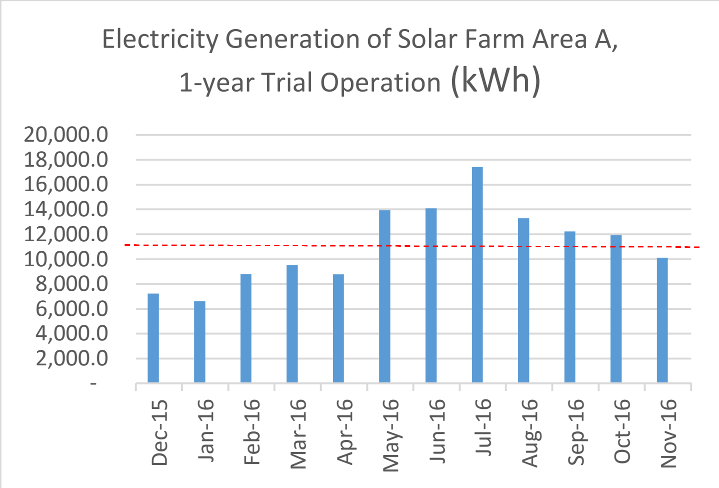

Fig. 17 Electricity Generation by Solar Farm Area A

Table 8 Electricity Generation by Solar Farm Area A

Month	Generation (kWh)
December 2015	7,229.7
January 2016	6,611.6
February 2016	8,796.5
March 2016	9,512.7
April 2016	8,784.2
May 2016	13,935.9
June 2016	14,089.4
July 2016	17,409.6
August 2016	13,284.1
September 2016	12,238.2
October 2016	11,919.4
November 2016	10,127.7
Total	*133,939.0*
Average	*11,161.6*

ENVIRONMENTAL ACHIEVEMENTS

Electricity Generation from Solar Farm

It was estimated that the annual electricity generation by the whole solar farm would be 1,100,000 kWh per year, which is equivalent to 770 tonnes reduction of carbon dioxide emission per year, or the annual consumption of 230 households, or planting of over 33,400 trees.

With the grid connection, the electricity generated by the solar farm is supplied to various facilities inside the plant, including screening facilities, ultra-violet disinfection system, sludge treatment facilities, E&M equipment inside the Workshop Building and Administration Building via the internal power distribution network. The electricity generated accounts for about 25% of the current annual electricity consumption of SHWSTW.

Fig. 18 Main Display Panel Showing Instantaneous Power Output and Accumulated Energy Generated by the Solar Farm

Solar Farm Monitoring Room

As mentioned before, the Solar Farm Monitoring Room established by DSD not only provides a control centre centralizing all monitoring equipment, including the CCTV system and the intelligent DC combiner box, for the solar farm, but also serve as education purpose to our next generation by raising their awareness on the adoption of renewable energy.

The Solar Farm Monitoring Room is located on the 1st floor of the Workshop Building, which was originally the central control centre for the sewage treatment plant before plant upgrading works in late 1990s. Subsequent to the relocation to the Administration Building, the original control centre became part of the workshop area for spare parts storage.


Fig. 19 and 20 Solar Farm Monitoring Room Before Renovation

In order to fully utilize the space available inside the plant and to minimize the cost required for establishment, DSD decided to renovate this former control centre as the new Solar Farm Monitoring Room.

This Solar Farm Monitoring Room now becomes part of the docent tour for the public, which elaborates in detail the effort made by DSD towards sustainable development of Hong Kong, and also the use of different forms of renewable energy, including solar energy and biogas, in its facilities. Educational materials including the operating principle of the solar system and an interactive experimental kit illustrating the efficiency of different types of PV panels under variable lighting intensity were also equipped to provide supplementary information for the visitors.

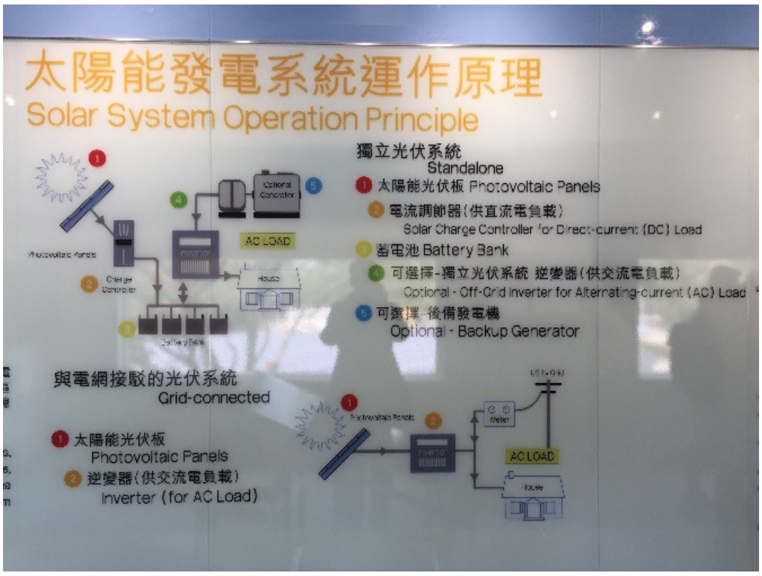

Fig. 21 and 22 Solar System Operation Principle and Experimental Kits

Pre-fabricated Concrete Supports for PV Panels

Instead of typical metallic frame support, concrete support was chosen for the solar farm because:

1. Hydrogen sulphide (H_2S) in the sewage treatment works led to a corrosive environment inside the plant area. Even if corrosion-resistant materials, e.g. stainless steel of grade 316, were used for the support, the lifetime would not be long which implied large amount of construction wastes from the solar farm. This was not preferred from environmental point of view; and
2. since upgrading, or even relocation of SHWSTW, was anticipated in the future in order to suit the development of the nearby area, mechanical anchorage of PV panel was not preferred as any demolition works might cause damages to the supporting structure. This would also result in disposal of large amount of construction wastes in case some or all PV panels had to be relocated in future.

Commissioning Ceremony of Solar Farm

To help develop Hong Kong as a low-carbon and livable city, DSD has kept on exploring the feasibility of using renewable energy in its sewage treatment facilities. Upon completion of this solar farm project in December 2016, the combined generation capacity of all PV systems in DSD facilities has reached about 1,250 kW. In view of the significant contribution of the project and to raise public awareness on the challenges brought by climate change, DSD organized the "Energy Revives the Sun – Commissioning Ceremony for Hong Kong's Largest Solar Farm" on 9 December 2016.

Over 300 guests from engineering industry, green groups, scholars and primary school students were invited to witness the commissioning of the Hong Kong's largest solar farm. DSD also invited the Secretary for the Environment as one of the officiating guests for the ceremony.

Fig. 23 Officiating Guests of Commissioning Ceremony

After the commissioning ceremony, docent tours were arranged for all guests to further introduce the solar farm system.

 

Fig. 24 and 25 Docent Tours Arranged for Guests

The solar farm project and the commissioning ceremony were extensively reported by the mass media. Moreover, substantial requests of site visits from various organizations and professional bodies were received. It was therefore considered that the project had fully achieved its objectives of raising public awareness on the adoption of renewable energy and demonstrating Government's commitment to combating climate change.

Fig. 26 and 27 Mass Media and Guests on the Event Day

After the commissioning ceremony, DSD had received overwhelming requests of technical visits from various professional bodies, including various divisions from the Hong Kong Institution of Engineers, and the Chartered Institution of Water and Environmental Management. More visits to the solar farm by the public are expected when the visit arrangement be launched in DSD's website in April 2017.

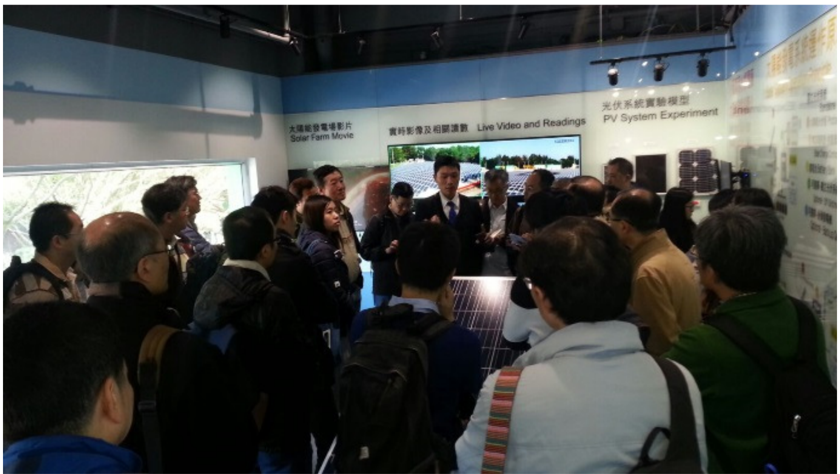

Fig. 28 and 29 Visit from HKIE Electrical Division

CarbonCARE® Action Label

Following the commissioning of the Hong Kong's largest solar farm, DSD received the CarbonCARE® Action Label 2016 from CarbonCARE InnoLab.

Fig. 30 and 31 Assistant Director / Electrical and Mechanical Received the CarbonCARE® Action Label 2016 in the Presentation Ceremony Held on 14 December 2016

CONCLUSION

Large-scale PV systems have been deployed in various DSD facilities, including sewage treatment works at Yuen Long, Shek Wu Hui, Stonecutters Island and Siu Ho Wan, to supply electricity to on-site E&M equipment. With the completion of the solar farm project in SHWSTW in December 2016, the total generation capacity of all PV systems in DSD facilities has reached about 1,250 kW.

DSD is committed to promoting environmental protection and incorporating such concepts into daily operation. In order to echo with the Paris Agreement and the Policy Addresses in 2016 and 2017 on combating climate change and the use of renewable energy, DSD will keep on collaborating with relevant stakeholders and promoting renewable energy and energy conservation by incorporating sustainable development elements into its facilities. Different forms of renewable energy including solar energy and biogas are currently supplying a total of 32 million kWh of energy for DSD's facilities, constituting about 10% of the departmental total annual energy consumption. DSD will continue to enhance the total energy management strategy for its facilities and extend the application of renewable energy, with a view to developing Hong Kong as a low-carbon and livable city.

REFERENCE

[1] Website of United Nations Framework Convention on Climate Change
http://unfccc.int/paris_agreement/items/9485.php

[2] 2016 Policy Address by the HKSAR Government

[3] 2017 Policy Address by the HKSAR Government

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