Sun Tracking Photovoltaic System

追蹤太陽的光伏系統

機電工程署
EMSD

Energy from the Sun

Solar Energy is a form of renewable energy which is abundant in our environment. The use of solar energy can help reduce greenhouse gases emission so as to combat climate change.

Solar energy can be utilized in many ways. One of the common ways is to make use of photovoltaic (PV) technology to generate electricity from solar irradiation of the Sun. This technology has been increasingly in use in Hong Kong to generate clean energy.

Ways to Improve Electricity Generation of a PV System

The majority of PV modules use crystalline silicon cells to convert solar energy into electricity and more recently, thin-film type amorphous silicon cells are increasingly used in PV systems. Conversion efficiency of PV modules generally ranges from 6% to 19% for commercially available PV modules on the 2010 market, with the thin-film type at the lower end and the mono-crystalline silicon type at the upper end.

To improve electricity generation of a PV system, we could either use higher conversion efficiency PV modules or allow the system more chance to be exposed to the solar irradiation. A simple and economical approach to improve electricity yield can be realized by incorporating a sun tracker into the PV system to maximize the exposure of the PV panels to solar irradiation thus increasing the electrical energy yield.

This pamphlet will outline the basic principle of a sun tracking PV system, types of the system and the issues to be considered when applying such system. A case study will also be included in this pamphlet for reference.

太陽能

太陽能是在環境中含量極豐富的一種可再生能源。使用太陽能有助減少温室氣體的排放，從而應對氣候變化。

太陽能有多種用途。其中一種普遍的應用是利用光伏技術來把太陽幅照能量轉化為電力。這種技術在香港的使用續漸增多，以用於生產清潔能源。

提升光伏系統產電量的方法

大部份用於產電的太陽能組件是晶硅電池板，而近年來薄膜型非晶硅電池板也漸見普及。在2010年市場普遍售賣的光伏組件的轉換效率一般由百分之六至百分之十九左右，當中薄膜組件的轉換效率較低而單晶硅組件則較高。

若要提升太陽能光伏系統的發電量，我們可以透過使用較高轉換效率的太陽能電池板或增加太陽能電池板的曝光機會。一個簡單和經濟的方法是應用太陽追蹤器於光伏系統內來增加光伏板的曝光機會從而提升其產電量。

本小冊子將會介紹太陽追蹤器的基本原理、種類及引入此系統時需要考慮的事宜。此外，本小冊子亦刊載了使用太陽追蹤器的個案研究供參考。

How Does a Sun Tracking PV System Work?

The output power of a PV system depends on intensity of solar irradiation falling directly onto the PV panels. For conventional PV installation at a fixed angle with the horizontal (say, around 22˚ in Hong Kong), PV panels will receive the most solar irradiation when they are perpendicular to the sun ray. However, the PV panels are only perpendicular to the Sun for a short period at noon each day. In the other time periods, the panels receive lesser solar irradiation at a factor equal to the cosine of the sun ray incident angle (θ) as illustrated in Figure 1 and solar irradiation received is lowest at sunrise and sunset.

追蹤太陽的光伏系統是如何運作？

光伏系統的輸出功率取決於直接落在光伏板板面的幅照量。傳統的光伏系統以固定角度安裝（如在香港與水平的角度約為22度），每天只在中午時分才正面面對着太陽光線，其餘時間的幅照量皆會按入射角的餘弦而定（見圖一），當中以日出及日落時分的幅照量最少。

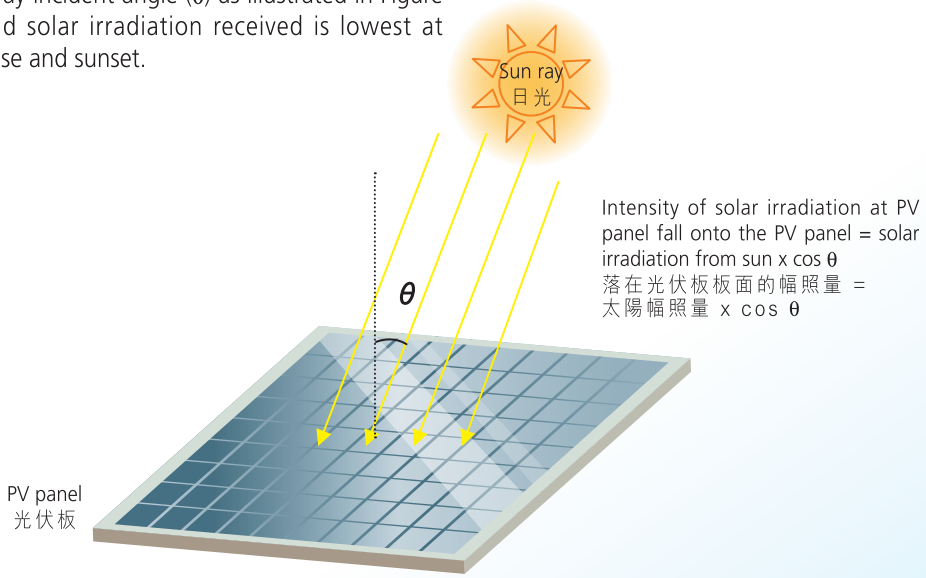


Figure 1: Solar irradiation fall onto the PV panels is related to the cosine of the sun ray incident angle (θ)
圖一：落在光伏板板面的幅照量按入射角的餘弦而定

Sun tracker is a technology for turning the orientation of PV panels such that they can always face the Sun at a very small incident angle so that the energy yield can be enhanced.

太陽追蹤器的作用是把光伏板的座向調節，使它與陽光組成的入射角長期保持最小，從而提升其發電量。

Types of Sun Tracking System

There are two types of tracking devices: those with single-axis tracking and those with two-axis tracking. A single-axis tracker has one degree of freedom that acts as an axis of rotation. It is typically aligned along the true North meridian and would rotate from East to West over the course of the day as shown in Figure 2. Inclination of the PV panels on the tracker would be adjusted manually at some periods of time (periodically every month or quarter of the year), to match the sun path at different months or seasons.

太陽追蹤器的種類

太陽追蹤器大致可分為兩類：單軸太陽追蹤器和雙軸太陽追蹤器。單軸太陽追蹤器擁有單軸的自由度，其軸一般會與北子午線排列成直線，日間會把光伏板的面向由東方轉動至西方來追蹤太陽（見圖二）。其傾斜角度須由人手根據太陽的軌跡作月份或季節性的調整（調整頻率大概是每個月或每季度）。

(a) PV panel faces east in the morning
光伏板在早上面向東方

(b) PV panel rotates to face west in the afternoon following the sun position
光伏板在下午按太陽位置轉向至西方

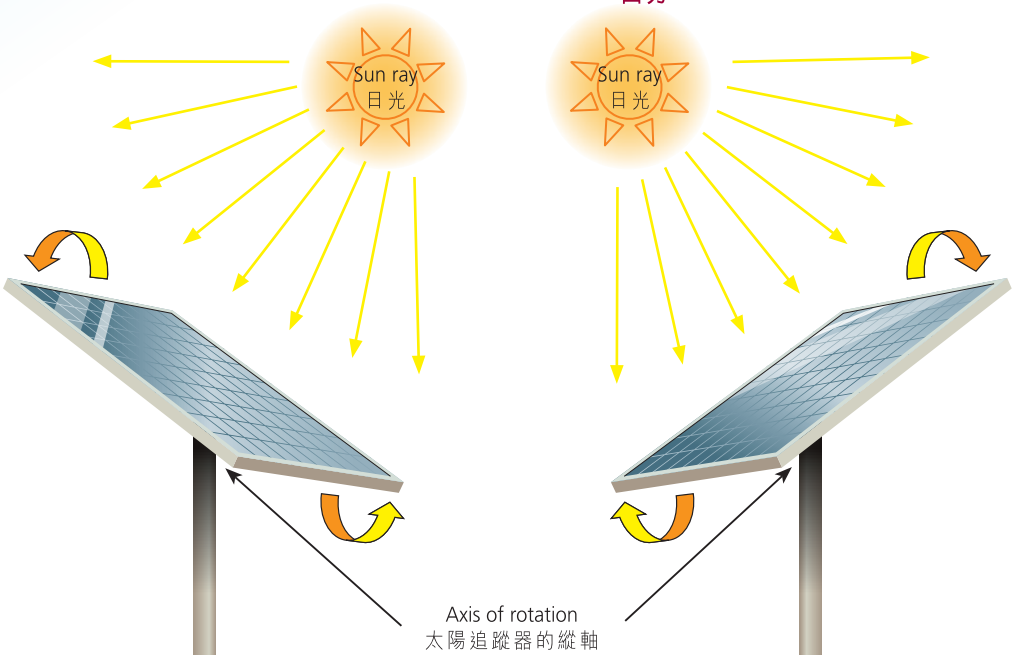


Figure 2: Illustration of a typical single-axis tracker rotating the PV panel gradually from east to west during the day
圖二：示意圖顯示典型單軸太陽追蹤器在日間按太陽位置漸進地把光伏板的面向由東方轉動至西方

A two-axis tracker (sometimes called dual-axis trackers, as shown in Figure 3) has two degrees of freedom that act as axes of rotation such that it can always face the Sun in an optimal position throughout the year. Two-axis trackers usually are more sophisticated. They have a primary axis that is set for inclination with the ground and a secondary axis for orientation along east-west direction.

雙軸太陽追蹤器擁有雙軸的自由度，旨在全天候追蹤太陽位置達致最佳幅照的位置。雙軸太陽追蹤器通常是較精密。它們的主軸是相對於地面水平設置，而副軸則和主軸成直角（見圖三）。

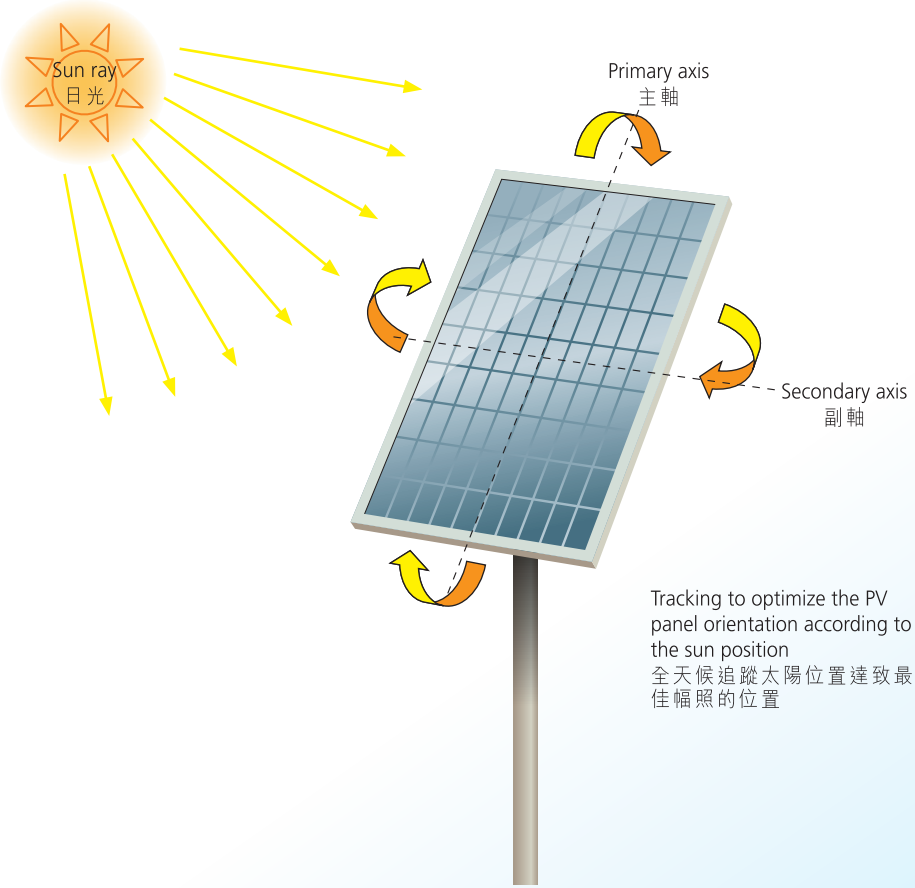


Figure 3: A typical two-axis tracker rotating the PV panel around 2 axes, i.e. one axis for inclination with the ground and the other axis for orientation along east-west direction

圖三：示意圖顯示典型雙軸太陽追蹤器，包括按地面水平設置的主軸及把光伏板方向由東至西變動的副軸

Energy Consumption of a Sun Tracker

Energy required for the movement of the tracking mechanism depends on what kind of tracking algorithm is adopted. For tracking the brightest spot in the sky, the tracking mechanism may adjust position based on real time light detection and therefore, the movement will be more frequent and it will consume more energy. For the time schedule algorithm, the number of movement is minimal and hence less energy will be consumed. In general, the consumed energy for real time light detection sun tracker would be around 1% of the energy yield of a typical PV system, whereas time scheduled sun tracker would normally be less than 1% of the energy yield of a typical PV system. Sometimes, a small piece of PV panel may also be installed next to the system to provide electricity for the sun tracker.

太陽追蹤器的用電量

太陽追蹤器會透過轉動來追蹤太陽。轉動所需要的電量是取決於追蹤器使用的追蹤方法而定。有些追蹤器會追隨着天空上的最大的光源來移動，由於根據實時光源的位置來追蹤，其移動量會較多，亦需要較多的用電量。使用預設時間式的追蹤方法來追蹤太陽相對地會比前者的移動較少，因而用電量也較少。一般而言，利用實時追蹤的太陽追蹤器的耗電量約為一般光伏系統產電量的約百分之一，而利用預設時間式的追蹤器的耗電量一般約低於其光伏系統產電量的百分之一。有些追蹤太陽的光伏系統會附加一塊小型的光伏板在系統內藉以為太陽追蹤器提供電力。

Increasing Yield by Sun Tracking

If a PV system tracks the sun position, the energy yield will be increased. With sun trackers, the radiation gains would be more significant on a sunny day when high solar irradiation is available. The gain would be less significant on a cloudy day. Refer to the case study below for detail.

透過追蹤太陽來提升產電量

如光伏系統能追蹤太陽的位置，產電量會有所增加。當烈日當空幅照量高時，使用太陽追蹤器所收集到幅照量的增幅會較顯注。在陰天時，收集到的幅照量則會有較少的增幅。詳情可參考下列的個案。

Maintenance Requirement of the Sun Tracking System

The sun tracker basically consists of a mounting pole and a small motor. In general, the maintenance requirement is minimal. Routine inspection or repair works upon failure of components will only be required on a need basis.

太陽追蹤系統的保養要求

太陽追蹤器的基本組件包括托架和小型馬達。一般而言，保養要求不多，只需作定期檢查以確保組件運作正常，或當部分組件損壞時進行維修便可。

Issues to be considered when Applying Sun Tracking System

When a PV system is planned to be installed, investment of small additional cost for adopting also sun trackers is worthwhile to be considered so as to increase the energy yield of the PV system. The followings are some technical issues that need to be considered:

- Sun tracking PV system should be installed in location that is unshaded throughout the day. Satellite TV dishes, plants and other buildings in vicinity could be potential shadings to the system.
- Since the PV panels are movable, more spacing will be required for the sun tracking PV system when compared to conventional fixed PV system. Moreover, adequate maintenance space should also be allowed.
- Lightning protection system may need to be reinforced to cover the newly installed sun tracking PV equipment should the existing lightning protection cannot adequately cover the additional equipment.
- As the PV panels are movable, they are more vulnerable to wind effects. Assessment should be carried out to ensure that the proposed location is structurally safe to support the system loading and wind effects. Qualified professionals should be consulted for advice if necessary.
- The potential of vandalism should be assessed if the sun tracking PV system is accessible to the general public.

使用太陽追蹤系統需要考慮的事宜

當計劃安裝太陽能光伏系統時，值得考慮增加少許成本一併配置太陽追蹤器藉以提升光伏系統的產電效率。以下是就配置有關系統需要考慮的一些技術事宜：

- 追蹤太陽的光伏系統應安裝在陽光無遮擋的位置。較大型碟式衛星電視接收器、樹木和鄰近的建築物等在日間某些時段中有可能遮擋光伏組件。
- 由於太陽追蹤器上的光伏板可移動的，安裝追蹤太陽的光伏系統比安裝傳統的光伏系統需要更多的空間。此外，應預留適當的空間作維修用途。
- 如果現有的避雷設備未能適當地覆蓋新增的太陽追蹤器組件，有關的避雷設備或需相應加強。
- 由於太陽追蹤器上的光伏板是可移動的，它們更容易受風力的影響。因此，應為擬定安裝的位置進行評估，以確保有關位置的結構足以承載系統的重量和風力。如有需要，應向合資格的專業人士諮詢。
- 應評估人為損壞太陽追蹤器光伏系統的可能性，特別是打算把系統安裝於可容易受一般人士接觸到的地方。

The sun tracking technology can effectively improve the electricity generation from PV system. For further information, please contact the Energy Efficiency Office of the Electrical and Mechanical Services Department.

Case Study

To find out the effectiveness of sun tracking technology in enhancing the electricity generation from PV systems in Hong Kong, two small-scale mono-crystalline PV systems with sun trackers were installed in a government venue in Hong Kong. Each sun tracker holds 3 mono-crystalline PV panels with a total rating of 450W per tracker and both trackers are grid-connected. For evaluation purpose, one tracker was fixed in its position like conventional PV installation (i.e. tilted and facing south) and the other tracks the sun position daily and adjusts the orientation of the PV panels accordingly.

Single-axis tracking systems were employed in the pilot project. The system adopted a time schedule algorithm to rotate the PV panel from East to West at 15° for every stepwise movement towards the Sun throughout the day. The system would face the East in the morning and would move towards the West during the day. It would stay standstill at sunset and return to facing East early in the morning at sunrise. Panel inclination was adjusted manually each quarter of the year to match the sun path at different seasons.

The year-round performance monitoring was carried out during the period from October 2008 to September 2009.

太陽追蹤技術能有效地提升太陽能光伏系統的產電量的效能。如需進一步資料，請聯絡機電工程署的能源效益事務處。

個案研究

機電工程署在一政府場所內安裝了兩套配備太陽追蹤器的小型單晶硅光伏系統，以了解在本地情況下使用太陽追蹤技術來提升產電量的效能。每套光伏系統有三片單晶硅光伏板共450瓦，並與電網接駁。在測試過程中，其中一組追蹤器像傳統的光伏系統般，固定在傾斜並向南位置，另一組則每天追蹤太陽位置，以作比較。

此項試驗項目使用了單軸太陽追蹤器，並用預設時間式的追蹤方法，每天東西旋轉來追蹤太陽。每次移動均會轉動15度角來把光伏板調向太陽。此系統會在早上向東面朝太陽，在白天隨太陽向西移動，日落便停留於西面，直至第二天清早，當太陽再從東方升起時，太陽追蹤器便會回復原來向東的位置，再重複追蹤太陽。其仰角會靠人手隨每季的太陽運行軌跡加以調節。

該試驗項目在二零零八年十月至二零零九年九月進行了為期十二個月的表現監測。

The analysis showed the increase in monthly yield by adding a sun tracker ranged from 5% to 32% with an average increase of 19% on annual basis. The solar irradiation gain on a typical sunny day can be increased by up to 22% through adoption of sun tracker. On a typical cloudy day, the received solar irradiation between the sun tracking PV system and the non-tracking PV system was almost identical as shown in Figure 4.

監測期內的數據顯示，有追蹤器的光伏系統能提升每月產電量介乎百分之五至三十二，而全年平均則提升了百分之十九。在典型烈日的日子中，使用太陽追蹤器可增加收集幅照量的幅度達百分之二十二，而在陰天裏則沒有明顯的增加（見圖四）。

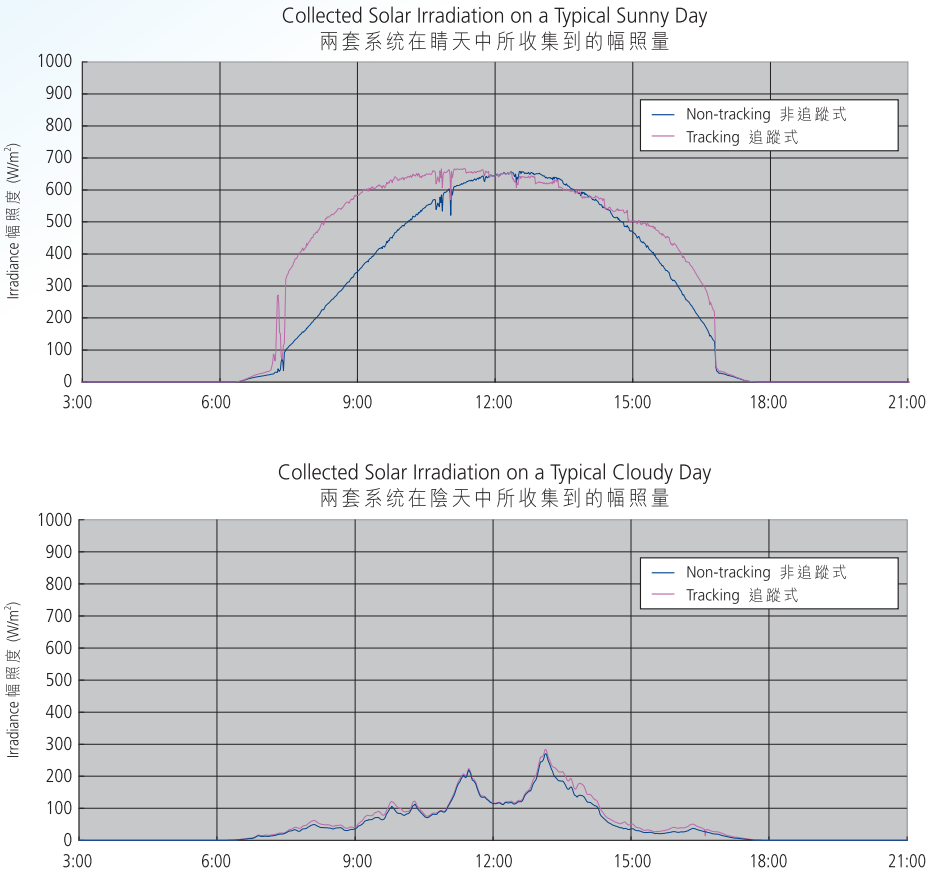
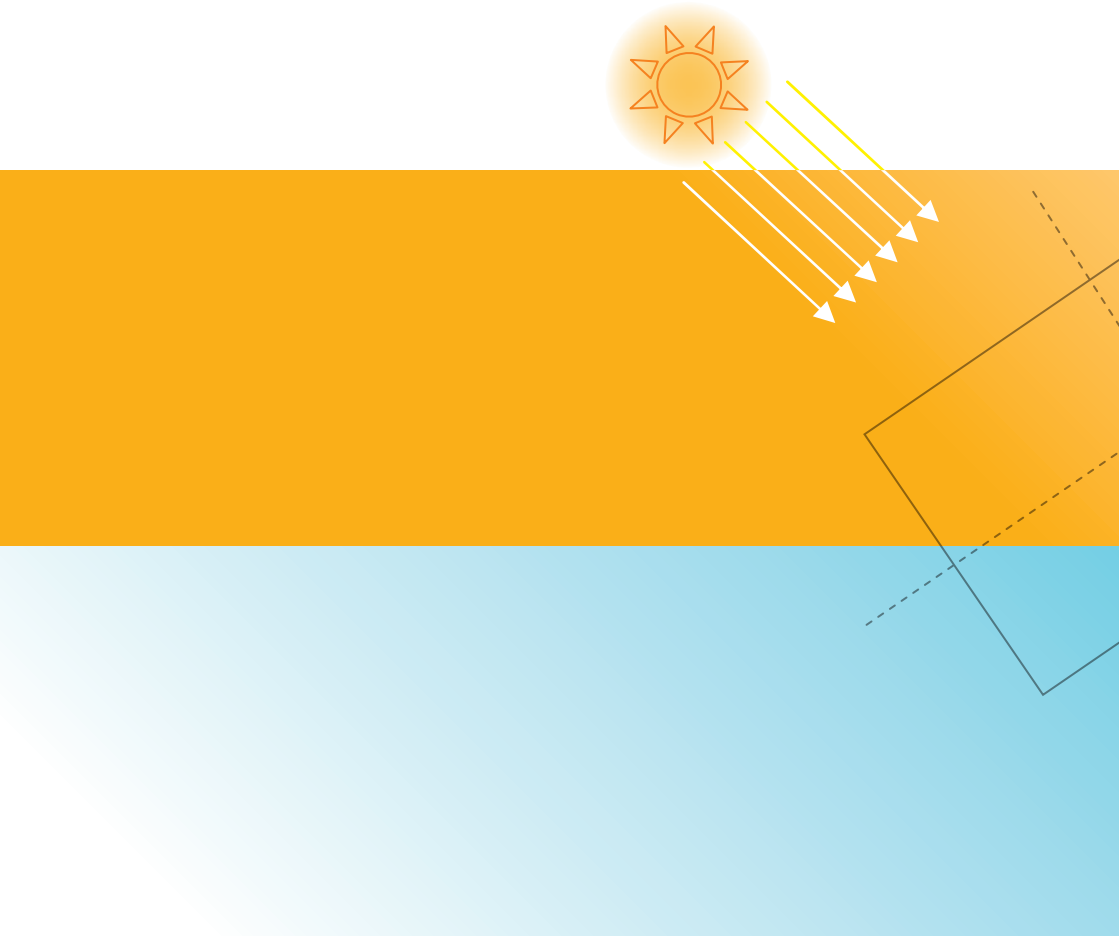


Figure 4: Collected solar irradiation on a typical sunny day and a typical cloudy day in the monitoring period
圖四：兩套系統在晴天和陰天所收集到的幅照量比較

In the case study project, the cost increase of the sun tracker was around 15% of the capital cost of PV panels. The relatively small capital cost invested in sun tracker has contributed to sizable additional energy yield.

此項試驗項目，引入太陽追蹤器令光伏板的成本增加了百分之十五。這項相對少量的投資頗顯注地提升了產電效率。

Figure 5: Sun tracking PV system at a Government venue
圖五： 在政府場所內安裝的配備太陽追蹤器的光伏系統



機電工程署 EMSD

機電工程署 能源效益事務處

Energy Efficiency Office

Electrical and Mechanical Services Department

香港九龍啟成街3號

3 Kai Shing Street, Kowloon, Hong Kong

電話　Tel: (852) 2808 3465

傳真　Fax: (852) 2890 6081

網址　Homepage: http://www.emsd.gov.hk

電郵　Email: eepublic@emsd.gov.hk

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