CLP'S FIRST OFF-GRID COMMERCIAL RENEWABLE ENERGY SUPPLY PROJECT FOR DAWN ISLAND

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ABSTRACT

The first off-grid commercial renewable energy (RE) supply system of CLP Power Hong Kong Limited (CLP) is being installed at Dawn Island which is a remote island in Sai Kung where a non-profit making drug rehabilitation centre is located and run by Operation Dawn. The RE supply system has been planned to cope with the ultimate electricity demand of the centre after her proposed development is completed in 2012. After considering various supply options such as submarine cable installation and overhead line connection, etc, RE was eventually selected to meet the electricity demand of the island. A hybrid system with a total installed capacity of 200kW, integrating solar panels, wind turbines and battery storage system, has been planned for implementation in two phases. The first phase with a capacity of 20kW has been successfully commissioned in January 2010 while the second phase is being implemented and will be completed in Q1 of 2012. The RE system will replace three existing diesel generators and reduce 70,000kg of CO_2 emission annually.

The establishment of the RE system for Dawn Island not only demonstrates CLP's commitment to providing a reliable, cost effective electricity supply to a drug rehabilitation centre on a remote island, it also realizes her core values of "Cares for the Community" and "Cares for the Environment". CLP also supports university research projects by providing the operation and performance data collected from this RE system to study the prospect of economic development of similar systems in Hong Kong.

This paper shares CLP's experiences in the design, construction and commissioning of the Phase 1 of this standalone RE system as well as in working with the residents on the island to enhance their knowledge in electrical safety and demand side management. A summary of the Phase 2 installation and various project challenges is also presented in the paper.

1. BACKGROUND

Dawn Island (also known as Town Island or Fo Tau Fan Chau) is situated in the southeast of High Island Reservoir and inside the Hong Kong National Geopark. The island is occupied by a drug abuser treatment and rehabilitation centre since 1976. The centre forms a small community on the island and serves about 50 to 70 rehabilitants. Before installation of the renewable energy system, the centre used its own diesel generators to meet its electricity demands. These generators were run on part-time basis to conserve fuel and save cost. In the late 90's, the centre had applied for permanent electricity supply from the power company. Traditional methods such as overhead line and submarine cable installations were considered but they would have substantial impacts on scenery and marine ecology. To cater for the redevelopment projects on Dawn Island, a detailed investigation on energy solution was conducted in early 2009. It was decided to adopt the increasingly affordable renewable energy option to supply electricity to the island.

First phase of the RE system has 19.8kW solar photovoltaic panels was completed with a construction time of just 5 months. Further expansion of the RE system under Phase 2 of the project is expected so as to meet the demand growth on the island. The system is built to meet the customer's ultimate needs and to comply with the utility supply standard under the context of Hong Kong. As local reference for commercial standalone renewable energy system of similar scale is non-existent, this paper shares CLP's experiences gained in technology selection, regulatory requirements, remote monitoring and control provisions, environmental considerations, contract management, site construction and demand side management from this RE Supply Project.

2. SUPPLY OPTIONS & SYSTEM DESIGN

2.1 Renewable Energy System Selection

Being a utility owned and operated supply facility, the RE system in Dawn Island has to be reliable, dependable, durable, and suitable for commercial operation, and solar, wind and ocean are possible renewable resources. Further investigation indicates that solar resources, because of availability of long term data from Hong Kong Observatory, can support the design of a RE system with high certainty. As Dawn Island is at the eastern side of Hong Kong, wind resources could be another viable alternative but there is no on-site data to support the development of large scale wind power facilities. Ocean (Tidal and Wave) is ruled out because of limited knowledge on ocean resources around the Island and uncertainties with the development of ocean technologies.

Another major consideration is the maturity of the renewable energy technology. Both photovoltaic (PV) panels and wind turbine have good track records in standalone operation in remote areas. In the Dawn Island case, special attention has been paid on the wind loading and salty environment withstanding capability of the RE technology. For a standalone RE system, reliable and efficient energy storage is needed to cater for time mismatch between the availability of renewable resources and load profiles. The commercially available energy storage technology has been scanned and deep cycle lead acid battery is considered as the most viable storage option for the system. To minimise the maintenance work, e.g. topping up battery fluid, maintenance free batteries are selected. Space footprint is another consideration in selecting the most suitable RE system.

Although there is plenty of land on the Island, the project has to ensure that any land resources granted by the Government will be efficiently used and the RE installations will have minimal disturbance to existing landscape. Last but not least, key components of the system have to be sourced from and warranted by credible manufacturers, and supported by skilful local contractors to ensure its reliability, durability and dependability. These requirements have been factored into the technical specification and engineering design of the system.

2.2 System Design

The off-grid photovoltaic supply system consists of PV panels, Inverters, Rechargeable Battery and Telemetry & Remote Monitoring. The following gives the details of the system design and configuration.

The project is divided into two phases. The Phase 1 system consists of 99 pieces of 200W PV panels in 6 string arrangement as shown in Fig. 1. Each string of PV panels is connected in parallel in a sub-array junction box to its DC/AC inverter, or PV inverter. In the sub-array junction box, diodes are fitted to prevent circulating DC current flowing between the strings caused by unbalance voltage generated. Lightning surge arresters are provided to protect the downstream equipment. Other balance-of-system (BOS) equipment is installed inside a 12 square metre plant room.

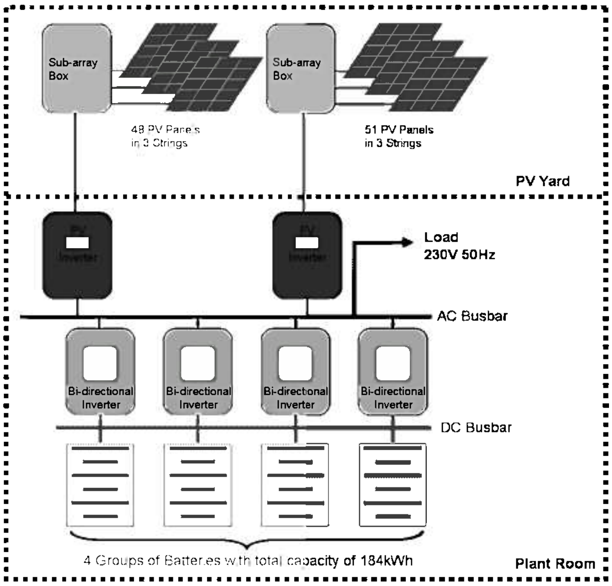

Fig. 1. System schematic of Phase 1 Dawn Island Renewable Energy Supply System

Fig. 2. Phase 1 PV yard

Fig. 3. Interior of Phase 1 Plant Room

All energy conversion and flow of the system are managed and controlled by two 10kW PV inverters and four 5kW bi-directional inverters. Bi-directional inverters convert energy to and from the rechargeable batteries with nominal storage capacity of 184kWh. The system supplies AC at 220V +/-6% and 50Hz +/- 2% to the customer.

The AC output from the PV inverters and bi-directional inverters are coupled at the AC busbar. The inverters work in coordination to control the power flow from the PV panels for charging up the battery or for supplying to the customer load. For instance, on sunny days, the energy from PV panels will supply to the customer load as well as to charge up the batteries. At nights or less sunny days, the stored energy in the battery banks will supply to the load. To protect the batteries from over discharge and preserve the necessary energy to maintain the control system, protection system and monitoring functions, normal supply to the customer would be temporarily suspended when the state of charge in the battery banks drops to 20%. The electricity supply will be restored when battery level rises again. Also temperature sensors are installed to the batteries and record the temperature in the data logger for monitoring.

DC busbar is connected across the batteries and the DC terminals of the bi-directional inverters. The busbar is the simplest method that helps to equalise the capacity of the batteries and avoids single battery group from being discharged excessively. It also helps to reduce power consumption of inverters as some of the inverters can be kept at standby when the consumption is low by setting the inverters co-ordinately. To match the development of the customer, Phase 2 of the project will have two standalone RE systems at about 1km apart. These standalone RE systems could be coupled by an interconnector in case of contingency. In addition to the PV panels, a small wind turbine will be built at each site to enhance the supply reliability.

2.3 Civil Design Considerations

2.3.1 Site Layout

Topography and minimum disturbance to site natural environment are the main considerations in selecting the site areas of Phase 1 and 2. The selected site areas are basically flat with small inclination towards the south, which on one hand does not require substantial site formation and on the other hand it allows sufficient surface drainage thus avoiding flooding risk. The site orientation is ideal for arranging the PV panel arrays towards the south. All the sites are exposed to the sun without obstruction by any major trees and vegetation, and therefore maximum energy can be obtained from the sun and wind whilst there is no impact to the existing natural environment. The plant room is located in such a way that its sun shadow would not cast on the PV panels.

2.3.2 Foundation Design

From geotechnical data, the topsoil of the site is highly decomposed volcanic tuff and the bed rock is quite close to ground level. With relative firm ground below the topsoil and in order to minimize the excavation and disposal of surplus soil which would otherwise require extensive transportation for such a remote island, some concrete masses were designed as foundation sitting on shallow firm ground for Phase 1. Both the foundation and superstructure for the PV supporting frames and the plant room in Phase 1 were designed to withstand super-typhoon.

2.3.3 Superstructure Design

In order to minimize in situ site work, both the support frames and the plant room were designed with prefabricated steelwork, hot dipped zinc galvanized to maximize corrosive protection to the salty atmosphere on the island. The structures are primarily screw fixing so that little site machining or welding is required. All components were optimally designed to allow manual handling or manoeuvring by simple lifting equipment on site.

Fig. 4. The foundation and superstructure for the PV supporting frames

Fig. 5. Precast paving blocks for access and maintenance paths of the PV yard

2.3.4 Materials

All foundation, paving blocks and perimeter fence of Phase 1 were designed so that they are capable of being reused in the later phases. Precast paving blocks for access and maintenance paths of the PV yard are basically made of recycled material. They are provided with planter holes to allow grass growing along the pathway in a controlled manner. In order to maximize RE use, solar bollard lights were installed for external lighting. The plant room roof was made of proprietary light weight cladding with thermal insulation equivalent or more superior than ordinary concrete so that mechanical ventilation to the plant room can be kept to a minimum yet the structural load and construction effort are minimized.

2.4 Telemetry & Remote Monitoring & Control

There is no fix-line communication network on the island. Wireless communication has to be used for the telemetry, remote monitoring and control of the system. A central data processing unit collects the ambient parameters and detailed performance of the system. The local PC captures the data for local display and stores for later processing. GSM modem is used to send key system status and alarms in the form of SMS messages to mobile phones and in-house TETRA telecommunication system.

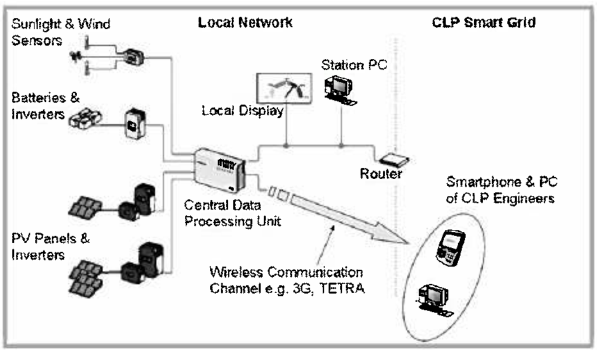

Fig. 6. Telemetry and Remote Monitoring System

2.5 Environmental Consideration

To supply the existing and future demands on the island, different technical options, including submarine cable, overhead line and renewable energy, have been considered. The first two options are not preferred due to reasons such as:

- potential impacts on the marine environment (for the submarine cable option);
- visual intrusion (for the overhead line option);
- marine navigation safety (for the overhead line option); and
- amenability to maintenance.

The self-sustained RE option can eliminate these issues. The selection of sites for the RE facilities has taken into consideration the modified nature of the area to further reduce potential environmental disturbance to sensitive receivers arising from the implementation of the Project.

Under the Environmental Impact Assessment Ordinance (EIAO), Phase 2 of this Project is classified as a designated project and Environmental impact assessment is required. The key potential environmental impacts of the project include air quality, noise, ecology, and site runoff during the construction phase. Potential operational phase impacts are expected to include noise, ecology and landscape and visual impacts associated with the PV panels, plant rooms and wind turbines.

3.0 SITE IMPLEMENTATION & SAFETY MANAGEMENT

3.1 Contracting Options & Contract Management

A "Design and Build Contract" approach is adopted by this project. The contractor is responsible for the design, supply, delivery, installation, testing, commissioning, and initial maintenance of the system. A steering committee which oversees the project team has been formed to manage relevant project issues arising from time to time. The project team draws professional support from operation and maintenance, asset management, engineering, contract & procurement, and technology research teams of the Company.

A Contractor Performance Management System (CPMS) has been used to evaluate contractor's performance regularly in 5 main areas:

- Safety, Health and Environment
- Project Management
- Field Quality
- Design Quality
- Customer Orientation

The evaluation results were reviewed and agreed with contractor. Based on the results, the contractor would formulate improvement actions, which were implemented and reviewed with the responsible engineer. The results were consolidated and benchmarked with other contractors.

3.2 Site Implementation

Before work execution, in addition to drawings and schematics, the contractor submitted the implementation plan and the method statements for the project. The purpose is to identify potential hazards and define risk mitigation measures for the whole construction process.

The construction of the system involved site clearance, concrete plinths casting for the plant room and PV structures, assembly of PV arrays and steel frames, erection of fencing, cable trenching, and in Phase 2, construction of wind turbine footings as well as the erection of wind turbines.

Construction materials and equipment were delivered to the island by helicopter and marine vessel. Minor excavation was required for slight adjustments to the site levels, construction of wind turbine footings and forming the underground cable trench. The excavated soil was backfilled on site immediately. A small quantity of broken concrete generated from cable trenching works was disposed of at public fill reception facilities.

The whole construction process was closely monitored. Revision to the implementation plan and the method statements were made where necessary and appropriate. Project meetings and site inspections were arranged fortnightly and on alternate days respectively. During erection of the PV system, following key points were observed:

3.2.1 Output voltage balancing among PV panels within the PV array

Each PV panel has its own output voltage and power characteristics. The effect acuminates across the PV string and causes voltage difference between strings. The voltage deviations among the strings limit the panel to provide its maximum power. The output power of the array will then be affected. A proper balancing work has to be carried out before installation. To further limit the undesirable circulating current flowing between strings caused by the voltage difference, blocking diodes are installed in series with each string.

3.2.2 Output voltage matching between PV arrays and inverter system

Inverter will demand suitable range of input DC voltage from PV arrays. PV array output voltage varies with solar radiation and temperature. Proper matching can ensure the inverter to function normally and deliver the expected performance. An output reduction up to 60% had been experienced in some extreme cases before the PV system was fine tuned.

3.2.3 DC rating of switching devices

It could be easily overlooked by frontline workers that AC switching devices are used for DC system. The DC breaking capability for an AC switching device is usually lower than its performance in AC.

3.2.4 Earthing connection of PV system, lightning system, and building services

The earthing of the standalone PV system is separate from the lightning protection earthing system. The separation will prevent the voltage surge to affect the PV panels, the voltage surge sensitive electronics components of the PV inverters, bi-directional inverters etc., when lightning discharges energy to the lightning protection earthing system. The PV system earthing is connected with the building services electrical earthing to provide a low impedance earth fault path for the activation of protective devices such as MCB's to operate when earth fault occurs. Standalone PV system requires a stable earth as a reference point for determine its output frequency. Proper earthing can avoid disturbance to the system.

3.3 Operational Phase

During the operational phase, the PV panels, wind turbines, control equipment and associated power distribution system are unmanned. Regular site inspections and maintenance works are required. Due to the remote location, transportation of heavy tools and equipment is not feasible.

During the routine inspection, visual inspection to the civil structures and building services is carried out. The performance of batteries and PV array are recorded and compared to previous data to identify any potential failure. Wildlife activity within the site is also monitored. Water supply on the island is limited. The PV panels are designed with feature of self-cleaning by rain water. Debris removal work will only be carried out on need basis to reduce water and detergent usage.

3.4 Safety, Health, Environment & Quality Management

The contractor was requested to establish an effective safety, health, environment and quality (SHEQ) management system, following the framework of Safe Systems of Work (SSoW), i.e. Work Details, Risk Assessment, Work Plan, Work Execution, and Work Monitoring.

The SHEQ Plan was prepared prior to the commencement of any site work. It included an environmental impact management plan and a compliance plan, and the means by which the applicable requirements shall be met. The following plans and reports were prepared by the contractor:

- SHEQ Plan with reference to the Factory & Industrial Undertaking (Safety Management) Regulations and the relevant Code of Practice.
- Risk Assessment Report that shall include identification of hazards (safety, health, ecological, fire, environmental, use of chemical substances, etc.) associated with the proposed works, evaluation of associated risks, and development of work procedures to mitigate the risks.
- Work Plan and Method Statements to define the scope of work and detailed implementation procedures. Risk mitigation measures and quality requirements are also included.
- A contract specific quality assurance plan.

Fig. 7. Supervisor communicates the work method statement with the workers and conducts PWRA

Fig. 8. Management SHE walk shows care to frontlines

During site implementation, the daily site safety, health and environmental (SHE) issues were monitored by site supervisor of the contractor. The supervisor performed pre-work risk assessment (PWRA) daily and monitored the workers' performance on site. Independent safety officer was employed to carry out safety audits. Formal inspection reports with follow up actions were prepared after each audit, which were followed up by the site safety supervisor. The findings were shared during biweekly project meeting.

Supervisory and Management SHE Walks were conducted. Instead of fault finding and punishments, the Walks aim at helping the frontline workers to improve their SHE awareness and performance by motivation. Management and frontline workers discussed recent SHE issues and shared the difficulties on implementation of recommendations. Frontline workers are credited for their efforts and initiatives on SHE aspect. All findings and comments from Audits and SHE Walks were recorded in central filing system. The gathered information were analysed and shared within the Company. Quality was monitored through inspections, material test (e.g. concrete and steel), progress reports and photo records on key steps.

4.0 DEMAND SIDE MANAGEMENT & ENERGY EFFICIENCY

The electricity utilisation habit has been changed after installation of the RE system. The island was powered by the customer's own generators which were switched off at scheduled periods. The electricity is now available 24 hours a day. To better utilise the solar power, load management measures have been implemented at the demand side. These measures shared the same objectives to:

- improve energy efficiency;
- optimize system performance; and
- improve residents' habit on using electricity.

Fig. 9. Safety and power-wise tips on using electricity for residents of Dawn Island

Load management measures investigated and adopted include:

- replacing defective and aged electrical appliances;
- providing advices on electrical appliances selection for future development;
- reducing power consumption at night by using timer switches and sensor switches; and
- educating the residents with safety and power-wise tips on using electricity.

These measures ensure that each kWh from the system could deliver maximum value to the customer on the island.

5.0 BEYOND ELECTRICITY SUPPLY

5.1 Cares for the Community and Environment

This first-of-its kind project has its significance to both engineering and community. The project not just demonstrates CLP's commitment to providing a reliable and low cost electricity supply for every customer who needs it, but also realises its core value of "Cares for the Community" through providing volunteer services to the island. Being the first commercial standalone RE system in Hong Kong, it shows that RE system is applicable in the territory. The project can fully comply with Environmental Impact Assessment Ordinance. With the commissioning of the whole 192kW system in early 2012, 70,000kg of carbon dioxide emission can be avoided annually. It has demonstrated the commitment of CLP on its core value of "Cares for the Environment".

5.2 Public Education

With the successful commissioning of the RE system on Dawn Island, it offers a real-life example of RE in practice, which serves as an educational platform outside the classroom. The project website provides a public interface through internet to share information about the project and knowledge about RE.

5.3 Research Projects

In addition to the green electricity, CLP hopes to leverage on the Dawn Island system to "generate" more knowledge supporting RE application and deployment in Hong Kong. Researchers and academics from engineering and science faculties of local universities were invited to submit research proposals making use of the operational data from the Dawn Island RE system. Eventually, CLP decided to support three local researches covering smart grid modelling, RE supply options for remote island and statistical analysis on the performance of RE system. Independently, two of the research projects have successfully obtained funding support from CLP's Education Fund. The research projects have started between September and October of 2010, and are expected to be completed in one to two years time. CLP engineers from the Dawn Island project team will work closely with the research teams to exchange ideas and provide input to the research projects.

6.0 SUMMARY

In early 2010, the first commercial standalone RE system was commissioned in Hong Kong and delivers electricity to the residents on Dawn Island. The system supplies electricity by photovoltaic arrays with a nominal capacity of 19.8kW. Further expansion of the RE system as under Phase 2 of the project is expected to meet the demand growth on the island

In this paper, experience in technology selection, regulatory requirements, remote monitoring and control, environmental considerations, contract management, site construction and demand side management are shared and discussed. The system is now in service and collecting relevant operating and ambient data. Further analysis of these data would provide more insight on the performance of different types of RE system and facilitate future development of similar RE installations in Hong Kong.

ACKNOWLEDGMENT

The successful commissioning of the RE electricity supply system mentioned in this paper are the concerted efforts of many stakeholders including the Agriculture, Fisheries & Conservation Department, Electrical & Mechanical Services Department, Environmental Protection Department, Lands Department, Sai Kung District Council and Operation Dawn. CLP appreciated very much the contributions of all these organisations for their full supports during the design and construction of the system.