Study on the New Business Model and the AC-DC System Design of an Island Street Lighting System

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ABSTRACT

Liuheng Island of a geographical area 128 km^2 locates at the east of Zhejiang Province, China. In 2017, the project of development planning as a smart energy island was initiated by the municipal government. This paper presents a design of the island SLS (street lighting system) as a part of the project. A new business model for the SLS operator with integrated energy is proposed. In the model, the SLS operator takes the responsibility of investing, constructing and managing the SLS and ensures the profitability and sustainable development of SLS by providing government, enterprise and public with energy and information services. Based on this business model, a design of the SLS is presented with integrated modern intelligence techniques and clean energy, including wind and PV generation, LED lighting, EV smart charging, environmental monitoring and video surveillance. In the paper, the requirements and innovative business model of the SLS are first presented. Then the basic functions of SLS and the design of AC-DC distribution network are given in detail. Finally, economic benefit analysis of the designed SLS are presented.

BACKGROUND

Liuheng locates in the southern part of the Zhoushan Islands at the southern end of the Yangtze River Estuary, with its location map in Figure 1. The jurisdiction consists mainly of five inhabited islands i.e. Liuheng, Fodu, Xuanshan, Duimianshan and Liangtan. Liuheng Island is the third largest one of Zhoushan Islands. The maximum distance between east and west of the jurisdiction is 27 km, the maximum distance between north and south 26 km, the total area is 128 km^2, and the permanent resident population is about 100,000.
Design and construction of the SLS (street lighting system) is an important part of smart energy island construction. To determine the development plan for SLS in Liuheng Island, it is essential to analyze the development prospects of the island, the current status and the future construction requirements of SLS.

Status of the Current SLS

There are 7,723 street lightings now (which are used for municipal management, traffic road and traffic tunnel, including 2,402 municipal sodium lamp and traffic road sodium lamps). There are three kinds of lighting lamps: sodium, energy-saving and LED. The total power is about 1356 kW. For now, annual street lamp costs about 48,000,000 yuan. The accumulated maintenance cost in 2017 is about 500,000 yuan. Due to the non-intelligence of street lighting facilities, the electricity cost and operation management fees present considerable financial pressure on the local municipal management departments.

Figure 1 Location of Liuheng Island

Future construction requirements of SLS

At present, Chinese lighting electricity accounts for about 14% of the total electricity consumption in the whole society, while outdoor road lighting accounts for about 30% of the total lighting consumption. Street lamps is a large proportion among the outdoor lighting. Due to the low intelligence, poor communication stability and low efficiency of lighting resources, street lamp's electricity bill and operation management cost have become a large part of municipal expenditure. In addition, current public street lamps, video surveillance, EV smart charging, environmental monitoring and other systems in the municipal department are separately planned, constructed and operated, occupying a lot of valuable urban land resources; all of them require a lot of manpower and material resources to operate, resulting in low resource utilization.

With the development of smart city, urban street lighting system technology is improving. Street lighting system is no longer just a simple lighting facility but an important part of smart cities and can play an important role in urban traffic safety, social security, people's life and city appearance.

In the overall planning of Liuheng Smart Energy Island, planners of Zhejiang Zheneng Xingyuan Energy Saving Technology Co . Ltd and Shanghai Fushun Energy Internet Technology Co. Ltd propose a new business model for the SLS service providers with integrated energy. In this model, the operator invests, builds and manages the SLS and ensure the profitability and sustainable development by providing energy and information services to government agencies, industry companies and public customers. With this business model, the SLS is designed, which integrates modern intelligence techniques and clean energy into the SLS, including wind and PV generation, LED lighting, EV smart charging, environmental monitoring, video surveillance, etc. The design of AC-DC distribution network is given, along with integration of data acquisition, transmission, processing and control execution. In addition, economic benefits analysis are briefly presented.

INDEPENDENT BUSINESS MODEL OF SLS

In China, road lighting system is generally designed and operated by the municipal department, and electricity bill is settled through the municipal financial allocation. For the development and operation of the smart energy island SLS, this paper proposes a new business model under the responsibility of energy service companies.

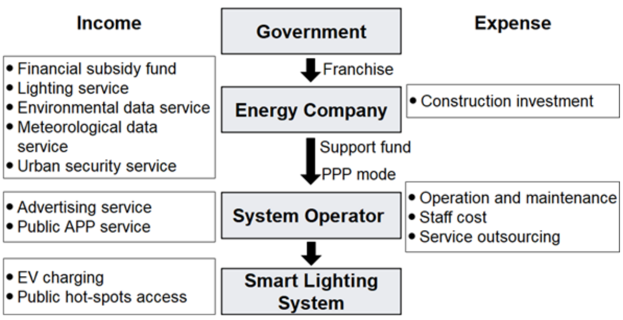

Figure 2 Independent business model of SLS

As shown in Figure 2, after obtaining the franchise rights from government sectors, integrated energy service company builds SLS through its own funds or joint investment with the government. After the completion of project construction, energy service company can recover the investment and profit in the following ways: 1) government financial fund subsidies, municipal lighting electricity charges and other related information service charges; 2) charging advertising service fees to professional advertising companies; 3) electrical charging service fee, WiFi hotspot charges, etc. through the online charging system. The annual expenses of the integrated energy service company include daily operation and maintenance expenses, personnel salary expenses and outsourcing service fees.

This is a terminal service for integrated energy at the local area. The new business model can change the traditional municipal management model, improve the efficiency and quality of municipal supporting services, and reduce the government's investment in urban infrastructure, the expense of daily operation and daily maintenance.

The key to the success of this business model lies in the comprehensive investment and compound income of the system: the more data information services superimposed in the system, the higher compound yield rate. On one side, government can reduce financial pressure during the early investment of municipal infrastructure, reduce the repetitive land occupation of municipal infrastructures, and obtain high quality energy services and extended data services through professional service outsourcing; on the other side, integrated energy service company can take advantage of professional technology, provide initial investment, a variety of professional services to improve the project's profitability and shorten the recovering cycle through a one-time investment.

DESIGN OF SLS

With the existing municipal conditions of Liuheng, the requirement of municipal services such as street lighting, EV smart charging, environmental monitoring and video surveillance, a smart lighting system is designed that integrates all functions into one. With the rich wind and solar resource at the island, the two kinds of clean energy are included, and energy storage units are equipped with considering the intermittency of wind and solar. To support the stable operation of multiple functional modules and connect the wind, PV energy and light storage system to SLS, a design of AC-DC hybrid micro grids are given, along with integration of data acquisition, transmission, processing and control operation. The following of the section gives the functional design, the network architecture design, voltage class selection, the layered control and communication architecture of SLS.

Functional design

SLS mainly consists of five sub-systems, i.e. wind and solar generation system with energy storage, intelligent lighting system, EV charging system, monitoring system and video surveillance system.

Wind and solar generation

Generation system consists of wind power generation and photovoltaic power generation, and is equipped with energy storage equipment.

Wind power generation of magnetic suspension fan is used, with rated power of 300W, output voltage of AC 12/24V, starting wind speed of 2m/s, rated wind speed of 11m/s, safe wind speed of 45 m/s, fan diameter of 50cm, height of 110cm, weight of 20kg. The efficiency is about 10% higher than that of the conventional fan, with good shape, small vibration during operation and small impact on no-rod road pole. The designed service life is 25 years.

PV power generation adopts special-shaped PV panels, with rated power of 300W, output voltage of DC 24V, energy conversion rate of 22%. The power generation is attenuated by 3% in the first year, and then 0.8% every subsequent year. Power generation in the first 25 years is no less than 80% of the first year. PV panels are streamlined and the design can reduces the effects of wind and is suitable for islands.

Energy storage system uses a maintenance-free lithium battery with a rated capacity of 100Ah, operation voltage of 24V and a service life of 5~8 years.

Smart lighting

The system uses LED lighting, with rated power of 100W, average daily illumination of 10 to 12 hours and 20Lux, a illumination range of 35m×12m. Control from data and control center can executed, i.e. any single light or a custom set of street lights can be under control. The system has automatic inspection function, which greatly improves the efficiency compared with the traditional manual inspection.

EV Charging

The charging pole is with rated power of 30kW, the input voltage of AC380V±15%, and the output voltage is adjustable DC. Charging system provides charging services for electric vehicles, and offers wired and wireless charging. The wired charging adopts DC fast charging method, which can complete the charging within one hour; the wireless charging adopts the electromagnetic induction type, and charge coil is embedded in the concrete of the charging station. In addition, a charging system of mobile device is provided for pedestrians to charge electronic devices. Users can charge by coin, credit card and scan code.

Monitoring

Monitoring system monitors meteorological data and environmental data. Meteorological data includes temperature, humidity, wind speed, rainfall, atmospheric pressure, solar radiation intensity, surface temperature, visibility, etc.; environmental data includes noise, PM2.5, CO2, acid rain, negative ions, etc.. After the data is analyzed and processed, it is provided to the meteorological bureau and the environmental protection bureau and released in real time through the city release platform, such as LCD display and WIFI hotspot.

The overall size of the monitoring device is 726×220×115mm, the rated voltage of power supply DC 48V, the operation power less than 15W, and the data transmission by RS485 bus/GPRS/RJ45.

Video surveillance

Video surveillance system records the real-time road conditions and provides them to the traffic control department. The monitoring equipment uses anti-corrosion, high-definition and high-speed smart ball machine with an input voltage of DC24V±25% and supports AC24V power supply with a power of 40W. The monitoring range is around 300 meters.

Network architecture design

Considering power balance, load demand and other factors, network architecture of the SLS is designed with an AC/DC hybrid system topology structure as shonw in Figure 3. Voltage levels and communication mode are also shown in Figure.

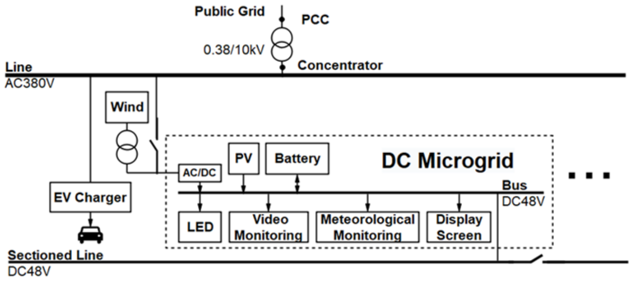

Figure 3 Network architecture design of SLS

DC micro-grid

A DC sub-microgrid is built in each intelligent road pole. PV power supply and load are directly connected to the DC micro-grid, and the magnetic suspension fan of wind power is incorporated into the DC sub-micro network through AC/DC conversion.

Considering the closeness of DC micro-source voltage and the DC load voltage in SLS and the importance of SLS in urban management, a double bus-bar structure is selected, as shown in Figure 3.

Taking account of the distance about 30m between adjacent road poles, and the generation and load of each pole in different working states at the same time, the adjacent sets of three road poles can be connected through the DC bus and its controlled switch. The DC micro-grid group is formed to realize the optimal operation of generation, energy storage and load in the pile group and improve the operation efficiency.

AC micro-grid

The structure of the AC micro-grid is similar to the that of the normal AC distribution network. Considering that the connection point of the AC/DC hybrid micro-grid of this project is on the AC bus, the AC busbar is selected as a single busbar structure in order to simplify the structure.

AC micro-grid uses a radial grid structure, and the DC micro-grid of the road pole is connected to the AC bus through DC/AC converter. Each AC micro-grid is connected to the public grid through LV/MV transformer. The public grid is used as back-up supply. Switching between the two operation modes of grid-connected and islanding can be realized through the breaker connected to the public grid .

Voltage selection

The AC micro-grid and the DC micro-grid of the AC/DC hybrid micro-grid are connected by a bidirectional converter. The voltage selection of the two micro-grids is discussed separately below.

The voltage of AC grid is set to 380V. To avoid large voltage drop, a set of road poles form an AC micro-grid group, connectted to a 10kV/0.38kV transformer and controlled by a dedicated concentrator.

DC bus voltage is selected to meet the requirements of the existing equipment. The standard of DC micro-grid voltage in China is still under study, and without uniformed standard.The DC 380V standard of Nano-Grids DC micro-grid by US Power Electronics System Research Center (CPES) has gradually been recognized by foreign industry. In the system, DC 380V is used for major household appliances, while DC 48V used for small desktop appliances and computers.

Rated voltage of load in DC micro-grid is 48V. If 380V is used as DC sub-bus voltage, a large number of DC/DC modules must be used in the system, resulting in increased cost. In addition, IGBT components in DC module increase electromagnetic interference and affect the work of various electronic devices. Based on these considerations, the voltage of DC sub-bus inside SLS is choose as 48V; considering that the distance between adjacent two poles is less than 30m, the height of the lamp pole is 10m, and the effective transmission distance of voltage as 48V can reach 50m. Thus 48V is a suitable voltage class for DC sub-bus between road piles.

Layered control and communication architecture

For the control structure of SLS, we adopt a layered control mode. The bottom layer control consists of the DC micro-grid of each SLS, and the upper layer control contains all SLS. The communication architecture is also layered as shown in Figure 4.

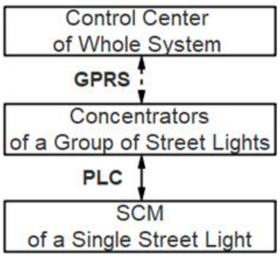

Figure 4 Communication architecture

The collector is installed at the 10kV/0.38kV transformer. The communication between each SLS and the collector adopts power line carrier mode, and the communication between the collector and the control center adopts the wireless communication.

There are two system operating modes: grid-connected operation and isolated network operation.

Optimizing the system economy is the goal of grid-connected operation. During high-demand periods, the energy of wind generation and storage system is preferentially used for all normal functions of the system, and the surplus electricity of wind generation is sold to public grid. The charging price consists of the peak electricity price of the grid ang an proportion of service fee. During the valley period, electricity is purchased taking into account the capacity of the energy storage equipment and the wind power generation, and the charging price is adjusted to the grid valley electricity price an proportion of the service fee.

Most of the isolated operations are in extreme natural weather. Under such a case, the public power grid is difficult to guarantee power supply and the SLS in isolated network operation ensures the basic functions. Considering the climatic characteristics of island, the extreme weather is mostly windy and heavy rain. If the wind turbine is intact, wind generation can be guaranteed under island operation mode.

Consider three adjacent DC micro-grids of SLS connected by DC bus. If all wind turbines with the rated power of 35kW, 10-12 hours of street lighting (100W), 24-hour monitoring (power less than 15W), 24-hour video surveillance (40W) and the capacity (100Ah) of the energy storage can be guaranteed in isolated network operation. If some wind turbine is out of work, wind turbine of the adjacent SLS can also meet its basic functions through the DC bus. If all the three wind turbines are in failure, energy storage equipment can provide the energy required for the basic functions, and the number of working lights can be appropriately reduced to extend the running time.

Control system needs to be modeled and analyzed in detail in further work.

COST BENEFITS ANALYSIS

The sustainable development of the designed SLS is mostly determined by its economic benefits. To analyze the economic benefits under its business model, it is necessary to consider construction costs, annual operating costs and annual revenue, which are listed in Table 2, Table 3 and Table 4 respectively.

Table 2 Construction Costs (*10^4 yuan)

Items	Price/ unit	No. Units	Subtotal
Wind-PV generation system	0.71	2402	1705.42
Smart lighting	0.85	2402	2041.70
EV Charging Pole	0.80	205	164.00
Environment monitor	2.00	28	56.00
Video surveillance	0.95	279	265.05
Hydrostatic monitoring probe	0.10	836	83.60
Display screen	1.50	410	615.00
Operation system	300.	1	300.00
Construction cost			1146.15
Land use cost			30.00
Total			**6406.92**

Construction costs can be divided into four major categories, namely equipment costs, operation system costs, construction costs and land use costs, of which equipment costs reached 50 million yuan, accounting for the largest proportion in the previous construction.

Table 3 Annual operation costs (*10^4 yuan)

Items	Price
EV charging energy	104.83
Pension and bonus	200.00
Management cost	52.31
Repair cost	52.30
Total	**409.44**

Operation cost is divided into two parts. One is the daily EV charging purchase cost. As the energy demand of charging pole is often large, the wind-PV generation of SLS cannot meet the charging demand, it needs to purchase electricity from the grid; the other part consists of human resources costs for daily operation and maintenance cost.

Table 4 Annual income (*10^4 yuan)

Item	Income
Government financial subsidy	72.06
Municipal lighting electricity charge	207.68
Environmental monitoring charge	72.06
Road monitoring service charge	72.06
Security service charge	72.06
Advertising service charge	410.28
APP advertisement charge	205.14
Personal charging services	149.75
Total	**1261.10**

Annual income consists of two parts: one is the government financial subsidy, and the other is the service charge. For the demand of various services, stable income (including government financial subsidies, municipal lighting electricity charges, data service charges, security service charges) is about 4.8 million yuan; the less stable income is from personal charging services, about 1.5 million yuan; unstable income is from corporate APP and advertising service, about 6.15 million yuan. However, stable income is still higher than annual operating costs, and ensures the annual profit positive.

Based on the estimated construction cost, the annual operating expenses and the annual income listed above, the estimated return on investment is about 13% per year, and the payback period is about 10 years.

In addition to the economic benefits, SLS integrates smart lighting, video surveillance, monitoring data, EV charging and other functions to optimize land resources, so that the least land creates the maximum value. SLS supported by AC/DC hybrid micro-grid technology also meet the development of integrated energy utilization.

Conclusions

Based on the development planning of Liuheng Smart Energy Island, this paper designs an innovative business mode for the island SLS and an AC/DC hybrid micro-grid system integrating functions of wind and PV power generation, energy storage, LED lighting, EV charging, environmental monitoring and video surveillance, and adopting hierarchical control communication architecture. It has two operating modes: grid-connected and isolated. An independent energy service company is responsible for the operation of the system, and cost benefit analysis shows that the system can meet the requirements of sustainable development. In the future research, dedicated and detailed modelling and simulation of the designed SLS is needed.