International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 572

A DEMONSTRATION OF BUILDING AND TRANSPORTATION INTEGRATION SYSTEM FOR SMART CITY

Xiaoen Li[a], George You Zhou[a, *], C.C. Chan[b], Chen Wu[c], Yi Zong[d], Shi You[d]

[a]National Institute of Clean-and-Low-Carbon Energy, NICE, Future Science & Technology City, Changping District, Beijing 102211, China

[b]Department of E&E Engineering, University of Hong Kong, Hong Kong 999077, China

[c]Beijing Institute of Architectural Design (Group) Co, Beijing 100045, China

[d]Department of Electrical Engineering, Technical University of Denmark, Kongens Lyngby 2800, Denmark

ABSTRACT

Building & transportation have been the major sectors for the energy consumption of modern city. The recent development of distributed energy resources is attracting extensive attention from city designers, primarily driven by the transition need towards a future smart city. Key challenges exist from planning, design, construction, build, operation and service due to the barrier in regulation and engineering practice between building, transportation and energy industry as well information technology & recent rising industry of the Internet of things (IoT). This paper proposed a novel energy system infrastructure to create a synergy to accommodate the diverse temporal and spatial features cross building, transportation, energy and information domain. In addition, this concept is carrying out in an official area for 2022 Beijing Winter Olympic game and is also discussing for the implement in NEOM, Saudi Arabia. This paper mainly discusses the latest progress of the demonstration for the 2022 Winter Olympic.

Keywords: smart city, BIPV, energy storage system, electric vehicle, solar energy

NOMENCLATURE

Abbreviations	
BIPV	Building integrated photovoltaic
CHY	Chinese Yuan
CIGS	$CuIn_xGa_{(1-x)}Se_2$
EV	electric vehicle
FCEV	fuel cell electric vehicle
s-s-h-c	solar-storage-hydrogen-charing

1. INTRODUCTION

Sustainability goals have gradually become one of the top priorities for future planning of a smart city, especially from the energy perspective driven by low carbon or even zero carbon initiatives. Major energy consumptions of cities are buildings and transportations, which are normally planned separately in most cases due to the different regulations & engineering practice, although both are getting more coupling features cross energy network with data-driven capability under application of the Internet of things [1]. For example, BIPV technology has made significant progress in recent years when integrated energy management becomes popular in smart building applications [2]. Applications of Electric vehicles (EV) & Fuel Cell EV are increasing quickly when autonomous driving is being controlled by emergent fog-computing instead of a centralized cloud platform [3]. All these major technical advancements are showing the same tendency of coupling mechanism with energy network as well as an information network at de-centralized level [4]. However, these key trends have been overlooked from a system design perspective, especially under the concept energy internet, with a critical focus on the transition of smart power grid into multi-energy grid infrastructure from distributed network perspective instead of edge node perspective.

Selection and peer-review under responsibility of the scientific committee of the 11th Int. Conf. on Applied Energy (ICAE2019).

This paper intends to investigate a design concept from an energy edge node perspective for smart energy eco-system of the future city so that the distributed network will grow upon the edge intelligence with self-evolving capability. When considering the building as stationary energy terminal and vehicles as mobile energy terminal, we can create an evolving model similar as nature eco-system formed by plants & animals, while plants are considered to be stationary eco-system terminals and animals are considered to be mobile eco-system terminals [5]. The analogies between these two eco-systems imply that an edge node coupling mechanism, between plants & animals in bio-ecosystem while between buildings & vehicles in city energy eco-system, are the key drivers for the evolving growth in sustainability survivals. A most interesting observation is that, the eco-system is only relying on energy cycle and matter cycle to keep the growth and sustainability, while city energy eco-system is heavily relying on energy cycle and information flow for the same goal. This critical difference is analyzed by comparing both eco-systems overall thermodynamic perspective.

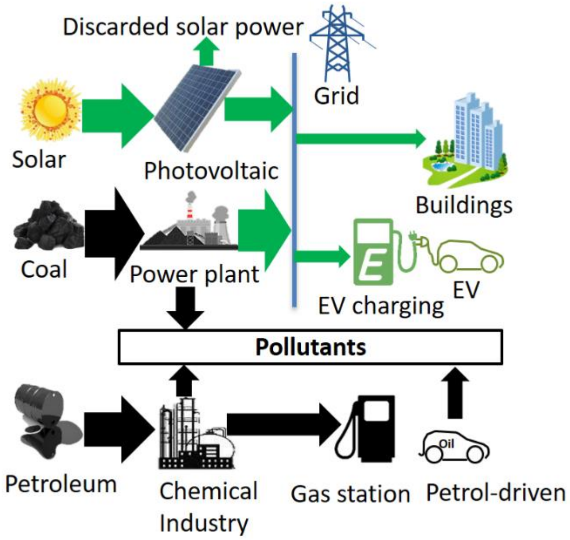
Based on these new findings, a solar-storage-hydrogen-charging (S-S-H-C) energy node structure is proposed as the key coupling mechanism and device at the energy network edge of the smart city.

2. SOLAR-STORAGE-HYDROGEN-CHARGING PROJECT

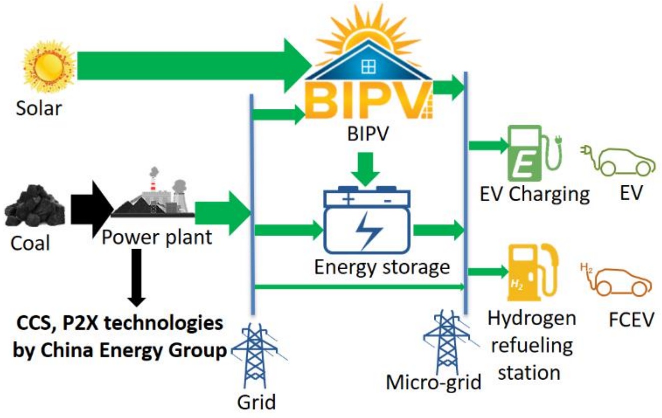
2.1 Project description

Increasing urbanization in recent decades has meant an upturn in the construction of high-rise and tall buildings worldwide, particularly in emerging economies. The energy flowsheet of the solar-storage-hydrogen-charging structure is shown in Fig. 1 b), which is a regional zero carbon energy demonstration as the office area of the 2022 Winter Olympic Game. In the traditional distributed energy system solutions, there is a lack of energy interaction and information exchange between buildings and transportation. For instance, the load demand for buildings and EV charger are under the same AC bus without energy and information exchange. While for the energy solution in Winter Olympic official area, the energy demand of building and transportation are coupled through the energy storage system and the building integrated photovoltaic (BIPV). Besides, the energy solution for NEOM, Saudi Arabia is a completely zero-carbon concept [6] and a similar structure is scheduling to bring into NEOM.

Moreover, energy publish & subscribe based evolution learning rule is developed based on the calculation of energy intelligence of eco-system at defined spatial or temporal scales. The extensive centralized data-driven mechanism is proven less sustainable comparing with scattered interactive data-flow mechanism driven by local physical property boundaries [4]. This situation points out that most efforts towards designing big-data driven energy system may not be enough to reach the sustainable goal as thermodynamics implies that energy to matter conversion with information stamping feature can eventually become dominant to evolve the ecosystem beyond sustainability.



a) The traditional solution for distributed energy system



b) Eco-energy system for 2022 Winter Olympic demonstration

Fig. 1 The energy flowsheet for the traditional distributed energy system and the energy system in 2022 Olympic official area

The demonstration is located on the north side of Chang An Avenue, Beijing, China. As shown in Fig. 2, six buildings are chosen as the demonstration, which will be built before 2022. Building A and F are the landmark buildings for official utilization. Building B, C and D are located at the exit of the subway. The building E is for commercial use.

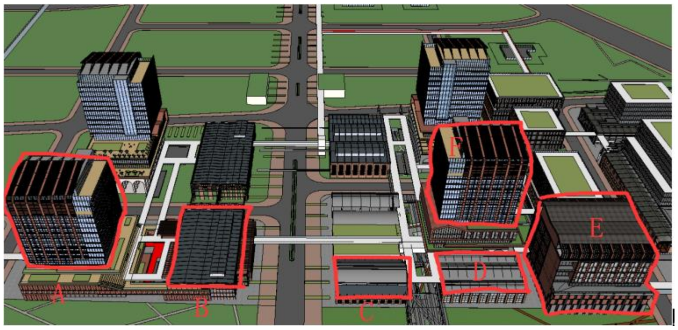


Fig. 2 Solar-storage-hydrogen-charging demonstration buildings for the 2022 Winter Olympic Games

2.2 Building integrated photovoltaic (BIPV)

In order to analyze the capacity of the BIPV system, the energy storage system and the hydrogen system, the effective area of illumination is analyzed as shown in Fig. 3. According to the sunshine condition of this region's longitude and latitude and the shielding situation of surrounding buildings, the arrangement of photovoltaic is determined. Besides, the size of standard photovoltaic (1.2 m*0.6 m) and the design scheme of building facade surface is also considered to calculate the number of PV panels used for each building.

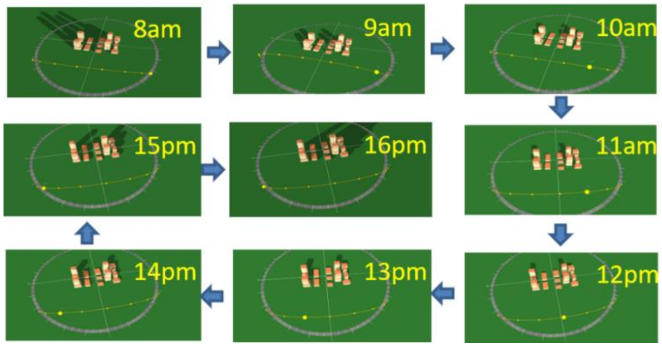


Fig. 3 Analysis of illumination effective region

To meet the design requirements and to realize the BIPV concept, the CIGS photovoltaic productions are used here. While the ordinary photovoltaic panels are used in buildings B, C and D, which are the construction of the subway.

According to the building design, the specific number of photovoltaic panels and power generation results are shown in and Table 1. Totally 7246 red CIGS standard panels are used for these buildings, including the roof of building A, the roof of building F, the south facade of building A, the south facade of building F, and the east and west facade of building E. While 7345 pieces of ordinary photovoltaic panels lay on the roof of building B, the inclined surface and flat roof of building C and the north and south sides of building D.

The base power of a single red CIGS standard component in Table 1 is 70 W, and that of a single black PV is 100 W. Due to different lighting angles and different shielding conditions, the photovoltaic panels at different locations have been converted according to the calculation of the effective area of illumination. The final regional total PV power can reach 1.04 MW, with an annual output of 1,353,000 MWh and a daily average output of 3.71 MWh. The subsequent economic analysis will calculate the average daily output of 3.7 MWh.

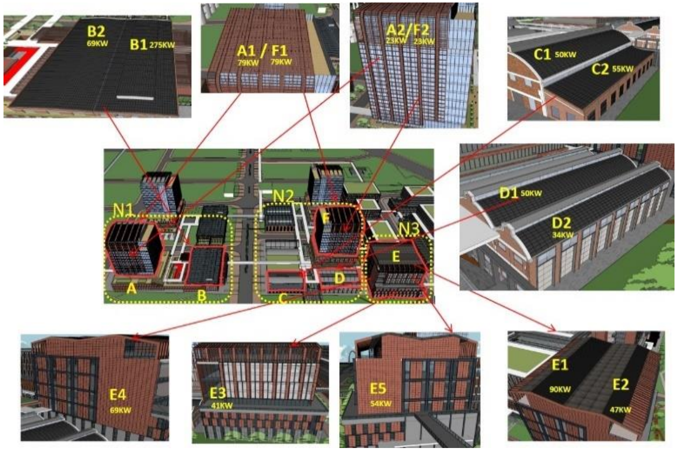


Fig. 4 Photovoltaic panel configuration of each building

Table 1 Photovoltaic panels and power generation in buildings

PV location	CIGS (red)	Traditional (black)	Power (kW)	Annual output (MWh)
A Sloping roof top（20°）	1125	0	78.75	102492.3
F Sloping roof top（20°）	1125	0	78.75	102492.3
A South Wall	463	0	23.43	30496.4
F South Wall	463	0	23.43	30496.4
B small roof	0	800	68.64	89375
B large roof	0	3203	274.82	357835
C Sloping roof top（30°）	0	555	55.50	72307
C Sloping roof top（10°）	0	540	50.00	65141
D north Sloping roof top（30°）	0	504	50.40	65663
D south Sloping roof top（30°）	0	336	33.60	43775
E north Sloping roof top（20°）	0	924	90.00	117264
E south Sloping roof top（20°）	0	484	47.14	61424
E south wall	818	0	41.40	53879
E east wall	1423	0	54.19	70525.9
E west wall	1829	0	69.65	90647.4
total	7246	7346	1039.70	1353813.5

2.3 solar-storage-hydrogen-charging system

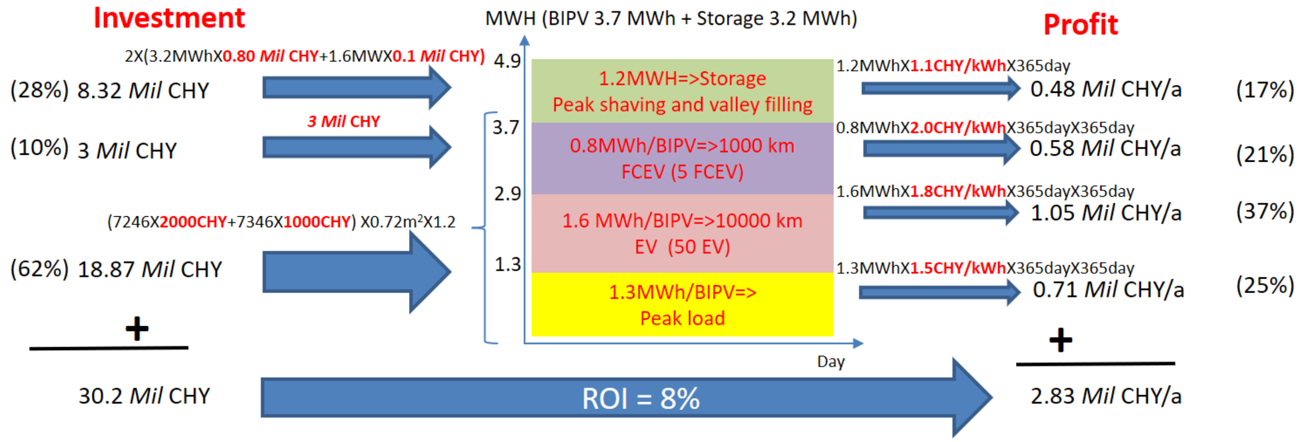


Fig. 5 cost and benefit analysis of the demonstration project

The configuration scheme of the solar-storage-hydrogen-charging system is shown in Fig. 6. According to the estimation from Fig. 3, 1.3 MWh/day of the total 3.7 MWh/day photovoltaic power generation is used for the peak load; according to the traffic planning and the plan of this official area, 0.8 MWh/day EV charging application is equipped, which can meet the traffic demand of 10,000 km/day. An FCEV hydrogenation with a capacity of 1.6 MWh/day is also applied, which can meet 1,000 km/day traffic demand. According to the power requirements of electric vehicles and fuel cell vehicles, the design of energy storage configuration requires a total of 3.2 MWh/day of battery energy storage, and a corresponding 1.6 MW converter. The energy source of battery energy storage (3.2 MWh/day) comes from the purchase of peak-valley price (1.2 MWh) and photovoltaic power generation (2 MWh). While the application of these 3.2 MWh/day storage energy is divided into three parts: 1.2 MWh for replacing peak load, 1.4 MWh for EV charging and 0.6 MWh for FCEV.

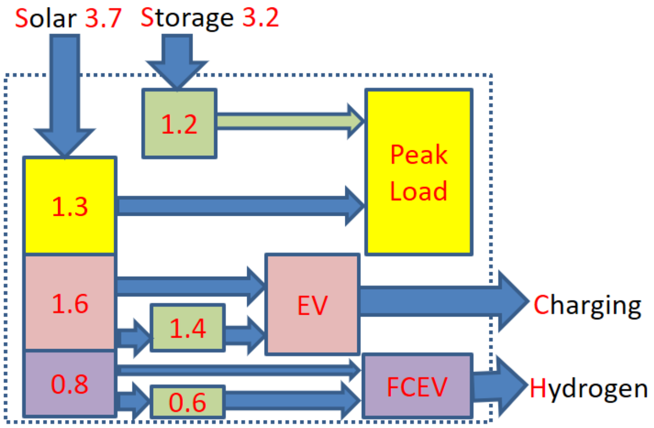


Fig. 6 S-S-H-C system configuration scheme (MWh/day)

3. COST-BENEFIT ANALYSIS

This application demonstrates a feature-based investment/return analysis, as shown in Fig. 5.

The investment costs mainly include the costs related to photovoltaic equipment, the costs related to energy storage converter and battery, and the costs related to hydrogen production and hydrogenation: (1) photovoltaic equipment cost. Based on current technical conditions, the cost of the CIGS photovoltaic panels and the ordinary photovoltaic panels is 2,000 CHY/m2 and 1,000 CHY/m^2, respectively. After considering inverter components and other auxiliary equipment costs, final photovoltaic equipment related operational cost is 18.87 million CHY, accounting for 62% of the total investment cost. (2) Energy storage converter cost. The investment and operation cost of 3.2 MWh battery is 800,000 CHY/MWh, and the corresponding investment and operation cost of 1.6 MW inverter is 1,000,000 CHY/MWh. However, limited by the current technical conditions, the lifecycle of the energy storage system is estimated to be ten years. Considering that the equipment is replaced once with a service life of 20 years, the investment of the whole energy storage system is 8.32 million CHY, accounting for 28% of the total investment cost. (3) the investment and operation cost of equipment such as hydrogen production and hydrogenation machine for 1000 km/day is 3 million CHY, accounting for 10% of the total investment cost.

The benefits include solar power benefit for peak load regulation, EV charging application benefit, FCEV hydrogenation application benefit and energy storage benefit for peak and valley regulation:

(1) 1.3 MWh/day of photovoltaic power generation is used to replace the 1.5 CHY/kWh peak electricity price in Beijing. This part of the income belongs to the national

energy group, and the income is 712,000 CHY/year, accounting for 25% of the total income. (2) EV charging provides quick charging service (30 W) by 1.8 CHY/kWh, providing 10,000 km of traffic application every day. The revenue is expected to be 1.05 million CHY/year, which is account for 37% of the total revenue. (3) Hydrogen storage system income is expected to be 2 CHY/kWh and the corresponding profit can rich to 584,000 CHY/year, accounting for 21% of the total income. (4) According to Beijing valley price (0.4 CHY/kWh) and peak price (1.5 CHY/kWh), the income of peak load regulation is 482,000 CHY/year, accounting for 17% of the total income.

The total investment cost for the solar-storage-hydrogen-charging system is 30.2 million CHY, and the total income is 2.8 million CHY/year, with a return rate of 8 %.

4. CONCLUSIONS

This paper discusses the building and transportation integration system based on the latest progress of solar-storage-hydrogen-charging demonstration in Beijing. With the continuous development and application of new technologies and new equipment, the underlying architecture of regional smart energy system is also in constant progress and evolution.

ACKNOWLEDGEMENT

This work is supported by the Chinese National Key Research and Development Program (2016YFE0102600) and the Demonstration on Key Technologies of Intelligent Management and Control of Distributed Energy System Program (ST930016sh04).

REFERENCE

[1] Wuni IY, Shen GQP, Osei-Kyei R. Scientometric review of global research trends on green buildings in construction journals from 1992 to 2018. Energy and Buildings. 2019;190:69-85.

[2] Shukla AK, Sudhakar K, Baredar P, Mamat R. BIPV based sustainable building in South Asian countries. Solar Energy. 2018;170:1162-70.

[3] Minami S. Toward a Successful EV and HEV Market in ASEAN: Lessons From the Past. Journal of Asian Electric Vehicles. 2017;15:1775-80.

[4] Zhou GY. Smart Energy Evolution Road-map Based On the Correlation Between Energy and Information. 10th International Conference on Applied Energy (ICAE2018).

[5] Zhang D, Mu S, Chan C, Zhou GY. Optimization of Renewable energy penetration in Regional Energy System. Energy Procedia. 2018;152:922-7.

[6] Asif M. Urban scale application of solar PV to improve sustainability in the building and the energy sectors of KSA. Sustainability. 2016;8:1127.