Case Study: The Analysis on the Benefit of Utilizing Smart Public Housing as a Virtual Power Plant

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I.   Abstract

Electricity demand in Chinese Taipei is concentrated in urban areas and peaks in summer, which is challenging for the system. Moreover, as an island, Chinese Taipei is not connected to other power grids so can only rely on its own electricity production. Furthermore, economic growth has tended to be coupled with increasing energy consumption. With the development of high value-added industries and the enhancement of living standards, the proportion of electricity demand over total energy demand will increase each year. Nevertheless, power facilities cannot be expanded due to lack of space, right-of-way and the opposition from local residents which also results it the difficulties of power supply. As the capital of Chinese Taipei, Taipei City has promoted the idea of building a virtual power plant with smart public houses through industry-academia-research cooperation in recent years. It is hoped that through the demonstration case of smart public housing in Taipei City, it will promote the development of emerging green energy and energy-saving industries, provide citizens with a better quality of life, relieve regional transmission and distribution pressure, and move towards the goal of a smart city.

II.   Promoting background of the smart public housing policy and demand management plan

In order to pursue higher quality of power supply, users' desire to obtain power information, integration of distributed power sources, the trend of energy conservation and carbon reduction due to climate change, and the continuous advancement of information, communication and power electronics technologies and cost reduction factors, smart grids and virtual power plant technology has been widely promoted in recent years. The concept of VPP is to construct an efficient, dispatchable and stable power plant from the demand side, within the operation plan. To realize the concept, basic input elements have been set up, including the construction of Distributed Energy

Resources (DERs) such as Renewable Energy (RE), Energy Storage System (ESS), and load management.

Taipei City represents 8.35% of the national total electricity consumption; moreover, the average consumption per capita is the highest among all nation, which is 16.5 kWh/day/capita compared to the nation's average 11.19 kWh/day/capita. In order to cooperate with the government's energy transition policy and support the operation of urban economic activities, Taipei City Government is urged to seek to introduce various low-carbon energy sources and integrate to develop virtual power plants, which can provide the power to maintain the city's innovation and vitality and build a high-quality living environment. Incorporating smart grid technology into its smart city promotion concept, and through the industrial development of innovative technologies, building user-group representative business models and open infrastructure, it can also promote the integration of smart city green energy industry into citizens' life.

III. Taipei City's Virtual Power Plant Demonstration Promotion Concept

In order to promote the construction of smart grid, Taipei City has a long-term plan for implementing the smart grid technology into the city. Campus, park, housing building, administration building, and commercial building are priority demonstration sites. In Taipei City, most of the electricity consumption comes from commercial and residential sector, about 48% and 31% respectively, industrial electricity only accounts for 0.24%. Since public housing is a permanent asset of the city government, and the population of public housing tenants are diversified, public housing buildings are ideal to test if the Aggregation Mechanism could support achieving the VPP concept and being widely spread in Taipei City, or even in all urban area. In this regard, Taipei City Government has chosen public housing buildings as one of its first target to implement smart grid technology. Until now, Taipei City Government has planned and started to build 20,000 public housing households belonging to a smart community, and, among them, 7,141 households will be equipped with smart grid technology.

The construction started with the Xinglong Public Housing area 1, in 2016, during the phase 1 of the project. It's the first public housing in Chinese Taipei to be incorporated into the smart grid. As an experimental phase, it started with a small scale program with 24 households involved, its facilities includes: (1) DERs such as rooftop solar PV, ESS and diesel generator; (2) sensing and control devices in households; (3) smart Building

Energy Management System (BEMS) and Home Energy Management System (HEMS); (4) smart charging system for electric vehicles; and (5) smart meters. During phase 2, 301 households, located in two buildings in Xinglong Public Housing Area 2, were also equipped with facilities mentioned above.

A project of this magnitude can only take shape with a close co-operation between several institutions. Taipei City Government owned the public housings and the Aggregator Platform and business model to lead the Smart Taipei project, with the Demand Response Bidding Program. In addition to providing public housing as an empirical field for low-voltage user demand bidding, Taipei City Government also supports part of the hardware funding for smart grid equipment required for public housing, plans to establish a user group representative for long-term development, and a series of publicity plans. The Ministry of Economic Affairs (MOEA) funds 25.23 million TWD of the subsidies through the "County and City Promotion of Commercial and Power Savings" policy. The domestic industry Chung-Hsin Electric and Machinery Manufacturing Corp (CHEM) supplied and design the hardware of smart grid technology in the demonstration public facilities. The second phase of the National Energy Program (NEP-II) Smart Grid Focus Center of Ministry of Science and Technology (MOST), brings technical support and implementation guidance, in-depth study of the promotion model, and assist the municipal government to establish user group representatives to participate in the Low-voltage Demand Response Bidding Program. It benefits from the consulting and expertise of Chinese Taipei Institute of Economic Research (TIER) and the research of the National Cheng Kung University (NCKU).

To implement the VPP concept into public housing, measures that first been taken were constructing hardware, introducing IoT technology, establishing the Aggregator Platform, and promoting the experience for scaling up, to achieve the establishment of a VPP in Taipei City. The smart public housing building includes DERs such as renewable energy generation; ESS, diesel generator and EV charger (see Figure 1). These facilities are integrated with an EMS to establish a microgrid which can smoothly and ideally switch the building's electricity between renewable energy, ESS and the power grid in different situations. Solar PV system, installed on the roof, can provide a certain percentage of the total power consumption of public electric facilities such as elevators, pump motors, public lightings, smart parking system, and EV chargers.

Figure 1: Public Facilities Constructed in the Public Housing Building

To verify possible benefits from implementing smart grid technology in households, Taipei City Government had chosen a part of the building's households to be equipped with the technology. Smart appliances, using smart home sensing control technology, lighting scenarios and air-conditioner control, can be automated and remotely controlled by residents via an APP on the control pad (see Figure 1).
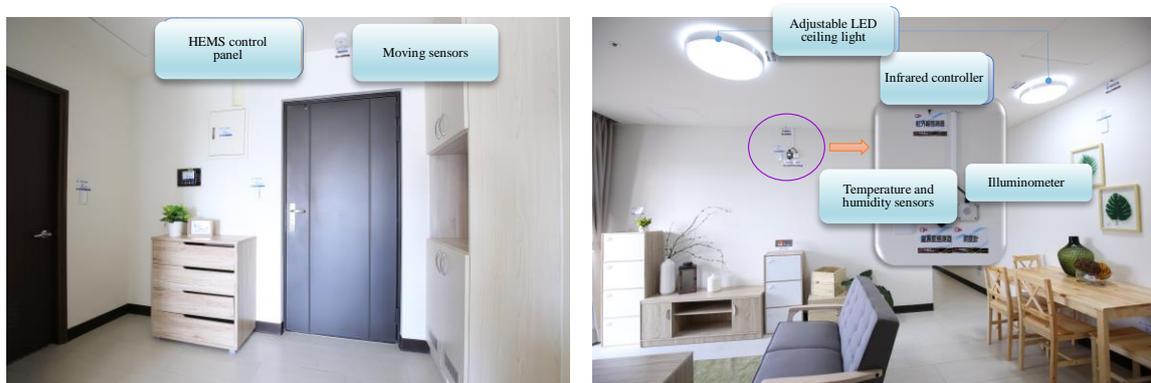
Figure 1: Household Equipped with Smart Appliances and HEMS

Low-voltage users accounted for 51.6% of electricity consumption during peak power consuming time in Chinese Taipei, which means that low-voltage users and users with meter rate lighting service also have the demand response potential. Therefore, Taipower Corporation launched the low-voltage user demand bidding trial plan in 2018. In 2018, Taipei City Government, the NEP-II and Chinese Taipei Power Company, proposed the experimental "Low-voltage Demand Response Bidding Program" taking advantage of the Aggregator Cloud Information Center as a platform.

IV. Analysis of the effectiveness of virtual power plant demonstration

It is estimated that smart communities could save 20% of energy consumption and 30% of water consumption for each household. Taipei City Government has been estimated that for six exemplary smart communities, there is a total of about 6,000 public housings on a total building estimated area of 593,500 m^2. The average energy and water consumption of each household in Chinese Taipei, without smart grid implementation, are 34 kWh/m^2/year of electricity and 3.65 m^3/m^2/year of water, respectively.

Participating in the demand bidding mechanism can also obtain rewards. Among them, considering the operating costs of the user group representatives, it is planned to use the total rewards paid by Taipower Corporation to be 1:1 as the user group representatives (Taipei City Government) and users (Xinglong Smart Community). That is, 50% of the total rebate will be provided as a user energy saving reward, and also each semester the reward will be given to 30% of the households which reduce the most energy consumption, in order to encourage them to keep participating in Demand Response. Assuming each household achieving 0.5kW reduction, with the highest monthly participation hours and the highest bid price, the estimated maximum reward can be obtained NT$ 1,800 per semester additionally.

In order to understand the impact of the introduction of a smart energy management system on different types of household electricity consumption, Xinglong District I selected a specific proportion of objects of different age groups and different life patterns from the self-acquired tenants like senior residents, young couples, students, home office workers (SOHO), etc., and make sure they are familiar with the use of related equipment. In order to verify the effectiveness of the introduction of the Smart Home Energy Management System (HEMS), the study also conducted a 14-month power usage analysis and found that the introduction of the Smart Home Energy Management System (HEMS) can enable users to achieve electricity visualization and household electric load regulation, thereby saving about 12% to 13% of electricity consumption.

Xinglong Public Housing Area 1 and 2 has been combined to participate in the Low-voltage Demand Response Bidding Program in order to verify the mechanism of Aggregator Platform. The first experiment for the Demand Response Bidding Program was executed January 10th, 2019, where households, equipped with HEMS, were accepted and gathered to participate to the bidding program. It achieved the reduction of 3.112kW during a period of 2 hours.

Statistics based on the aforementioned data also show that the introduction of the system has considerable energy-saving and load control effects, and has the opportunity to lead to more positive effects. It can be seen from Table 2 that as households become more familiar with the operation, use of equipment and platform mechanisms, the implementation rate can increase from 6% to nearly 27% in April. Therefore, it goes without a doubt that through better communication between the Aggregator and users, further savings in electricity can be achieved.

Citizens, gaining more awareness toward energy saving, could get more and more involved in the energy service, by means of the Aggregator System. The Aggregators thus would be established and could then participate to different kinds of energy services. The development of the Aggregator System along with the liberalization of the electricity market will contribute to achieve the VPP concept, a dispatch and large VPP within Taipei City. If the VPP concept is extended to all urban area in Chinese Taipei, it is expected to partially solve the overall challenges mentioned before, especially in the enhancement of spinning reserve. By increasing the PV generation capacity according to Chinese Taipei's 2025 solar goals, the Demand Supply curve will tend to look like a duck curve, where the help from Demand Side could be useful during morning or evening time, when the load is high and the PV generation is low.

V.   Replication and promotion of smart public housing and virtual power plants

Buildings are incorporate in complex that can communicate together, forming the Xinglong Smart Community with its own CEMS. The government carries out the idea of smart communities by meeting the life needs of residents through intelligent services. The complexes include meeting room, disaster prevention center, health care center, property management space, park, kindergarten, and home for the elderly, public library, smart farm, smart parking and other facilities. In case of power outage or emergency situation, the CEMS can operate as a VPP, using its communication mechanism to dispatch the energy resource, achieve real-time dispatching, unload demand, perform energy storage scheduling, and public facilities demand management from one building of the community to another. It thus allows to increase the energy efficiency and decrease the labor cost.

Industrial restructuring and policy encouragement have also accelerated the Smart Grid implementation in the urban area. Taipei City has thus become a demonstration object for

smart cities, looking forward to export successful experiences to the international market, and stimulating growth of the smart energy industry. Although smart grid technologies can be replicated, it takes extra efforts for government officials, architects, constructors, electromechanical technicians, and ICT vendors to introduce these technologies to their existing area of expertise. Therefore, Taipei City Government compiled and published the "Taipei Public Housing Smart Community Construction Reference Manual" to share its experience to the public and other city governments, both domestic and overseas to assist in the implementation of smart grid technology and the development of relative standards.

VI.   Conclusion and Outlook

The construction of the virtual power plant is based on the smart grid, integrating energy-saving, renewable energy, and information and communication related industrial technologies to expand the potential of regional load regulation and the use of green energy. As mentioned above, using smart public housing as the first demonstration point to introduce related technologies, the installation of a home energy management system (HEMS) can achieve an energy-saving effect of 13%. Moreover, the first experimental use of the Aggregator Platform for the Demand Response Bidding Program, for low voltage users of the Smart Communities, has been performed recently. It has shown promising results and encourages the enhancement and development of this policy. Smart technologies can now be integrated in such a scale, in other kind of buildings as well. With the liberalization of the electricity market, other energy services will additionally open and will establish a Virtual Power Plant that can efficiently dispatch and stabilize the power supply, maintain urban innovation and vitality, build a high-quality living environment, integrate green industries into citizens' lives, establish a vision for urban development, and create a low-carbon smart city.