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Apartment to grid (A2G) paradigm for demand and cost sensitive residential complex energy management

Nah-Oak Song [a], Dongjun Suh [b], Dan Keun Sung [a], Seongju Chang [a,*]

[a] Korea Advanced Institute of Science and Technology, 291 Daehak-ro, Yuseong-gu, 34141, Daejeon, South Korea
[b] Korea Institute of Science and Technology Information, South Korea

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ABSTRACT

As a special form of microgrid, an apartment to grid (A2G) system is conceptually designed and proposed for demand and cost sensitive energy management based on the energy implications and electricity consumption characteristics of apartment complexes in Korea. The A2G system aggregates generators as well as loads, and its energy management decisions are made by A2G System Manager with energy profiles from the aggregated components in the system. Fundamental factors such as energy policy, energy optimization criteria, and fair benefit sharing issues are dealt with exemplary scenarios and case studies. Load shifting/shaping can be easily achieved by the coordination of the A2G system components which are already *closely and densely aggregated* unlike those components in a typical microgrid as well as V2G. Then, a network of A2Gs, namely an A2G Network is introduced as a business model to promote the benefit of aggregation. The main contribution of the proposed A2G system comes from it's innate nature, *aggregation* of its components; both economic benefits as well as system stability could potentially be achieved through more effective load shifting/shaping by the coordination of the existing aggregated A2G system components.

1. Introduction: Reference models & motivation

The traditional electrical grid was originally designed to deliver power from power generators to customers and has served customers mostly well for more than a century. According to the U.S. Department Of Energy (DOE), today's electricity system is 99.97 percent reliable, yet still allows for power outages and interruptions that cost Americans at least $150 billion each year-about $500 for every man, woman, and child. Over the last few decades, peak demand for electricity has been tremendously increased due to population growth, more electronic appliance reliance and global warming, which may cause massive blackouts. More blackouts are expected mainly because of rapidly growing peak demand for electricity as well as the lack of situation/risk awareness triggering prompt coping responses.

This centralized unidirectional electricity grid is no longer able to satisfy our 21st century's living standards. To fulfill modernized energy consumers' requirements, the current electricity grid has to be evolved with the information and communication technology (ICT) toward so called "smart grid." ICT would enable a smart grid to have two-way communication, thus to improve the ability for situation/risk awareness which leads prompt coping responses.

To make the electricity grid be less centralized, a μGrid concept namely microgrid was proposed [1]. Within the microgrid of a local community, varieties of small-scale power generators are locally installed to provide electricity to the consumers within the community boundary. Therefore, the loss due to delivery and distribution of electricity could be reduced and local consumers are provided with more reliable and cheaper electrical power supply. Since a variety of small-scale power generators in a microgrid make the corresponding local community to be more independent from the macrogrid, the microgrid could be much securer in an emergency situation such as a sudden blackout in the macrogrid by simply isolating itself from the macrogrid [1]. Thus, the electricity provision in a microgrid becomes not only economical but also much secure and reliable than ever before. Consequently, its energy management efficiency becomes a critical issue and has been studied by many researchers as in [2–8]; the optimal operation of energy management system has been applied to a microgrid either in islanded mode [2] or in grid-connected mode [3–8].

In the meantime, the V2G (vehicle to grid) concept was first introduced by a research group at University of Delaware [9]. The basic concept of V2G is utilizing the power discharging capability of electric vehicles (EVs) equipped with batteries, hybrid engines, or fuel cells; electric vehicles could provide electricity to the power

* Corresponding author. Tel.: +82 42 350 3627.
E-mail addresses: nsong@kaist.ac.kr (N.-O. Song), djsuh@kisti.re.kr (D. Suh), dksung@ee.kaist.ac.kr (D.K. Sung), schang@kaist.ac.kr (S. Chang).

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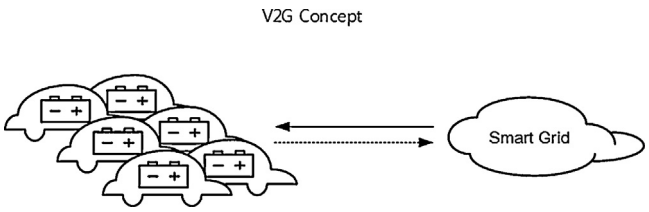

Fig. 1. Bi-directional energy transfers between vehicles and smart grid in V2G.

grid as shown in Fig. 1. Precise control of charging and discharging of these aggregated EVs would enable the V2G system to respond to the peak demand promptly and may demonstrate its potentially significant economic asset while meeting various driving requirements for the EV drivers [10].

As smart grid evolves, many researchers have also paid attention to the energy management for both residential and commercial buildings. Home Energy Management System, called HEMS, is designed to manage energy usage at a single home environment while Building Energy Management System, called BEMS, is aiming at managing energy usage in commercial buildings [11–14]. Similar to HEMS and BEMS, an apartment to grid (A2G) system manager is also for managing energy usage; the target is, however, an apartment complex where a great number of residential units are aggregated in a densely arranged form. Some apartment complexes in Korea even have a few thousand units hosted in high-rise buildings as shown in Section 2.

According to the Statistics in Korea, most Korean people once lived in single houses around 1980. Only 7% of Korean people lived in apartment complexes at that time. As population grows and the typical industrialized lifestyle of Korean society becomes more modernized and westernized, the spreading ratio of apartment housing has amazingly increased up to 59% in 2010. Since its escalation trend seems to be continued as shown in Fig. 2, the dominance of the apartment complex as a main housing style in Korea is expected to last quite a while [15]. The same trend of the popularity toward apartment complex has appeared in China and there are many ongoing apartment housing constructions in the large cities in China. By being motivated through the concepts of microgrid and V2G as well as the objectives of HEMS and BEMS, apartment to grid (A2G) system is conceptually designed and proposed in this paper based on the energy implications and electricity consumption characteristics of apartment complexes. The primary significance of A2G system is derived from its innate nature of *aggregating* A2G system components. Through this, economic benefits and system stability can be acquired by having more effective load shifting/shaping based on the coordination of existing aggregated A2G system components.

This paper is organized as follows. The main concept of A2G system is introduced in Section 2, and its operational mechanism is illustrated in Section 3. The communication mechanism and energy management process of A2G system are introduced in Sections 4 and 5, respectively. In Section 6, interrelated A2Gs called A2G network is developed as an extended model. Lastly, Section 7 concludes this paper with final remarks.

2. Apartment to grid (A2G) system

Apartment to grid (A2G) system is conceptually designed and proposed by being motivated through the concepts of microgrid and V2G as well as the primary objectives of HEMS and BEMS. Unique context and energy management implications of an apartment complex are fully investigated and utilized to make the concept of A2G system beneficial to all the residents living in apartment complexes. The objective of A2G system is smart energy management in an apartment complex through optimized control of aggregated components in the apartment complex.

To take advantage of the concept of microgrid, the A2G system contains varieties of power generators to be more independent from the macrogrid: variety of power generators could be combined heat and power generators (CHP), wind power generators, photovoltaic (PV) generators, and fuel cells. In addition, the A2G system also aggregates the devices which are capable of providing power such as electric vehicles (EVs) of the residents and energy storage systems (ESSs).

2.1. A2G system components

A2G system is aiming at smart energy management in an apartment complex through aggregation and coordination of its system components. A2G system components could be divided into two groups: loads which are consuming power and generators for providing power. The aggregated loads could be electric vehicles, energy storage systems, or general electrical loads: general electrical loads may include the power demands from household appliances, water pumps, and electric devices for common use to serve apartment residents such as elevators, lighting fixtures for the stairs and public places as well as surveillance cameras. The aggregated generators are power generators which actually produce electrical power including renewable energy sources, combined heat and power (CHP), and fuel cells. The aggregated generators also include electric vehicles and energy storage systems which are

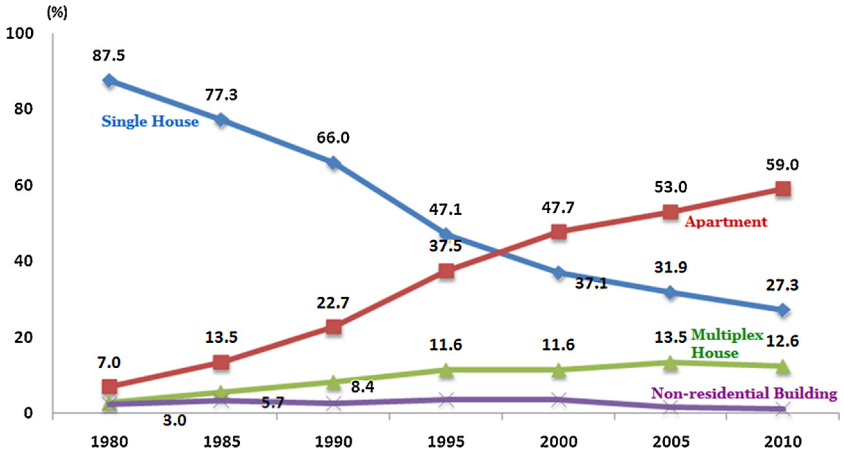

Fig. 2. Quantitative profiles of different housing forms in Korea [15].