Case Study of a Positive Energy Community for Renewable Energy Sharing

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Abstract

In this paper, we developed a positive energy community for renewable energy sharing community and investigated the positive energy performance of the proposed community compared with conventional community. The selected case study positive energy community has 56 houses and 2 non-residential buildings. This positive energy community is composed of building integrated photovoltaics (BIPV), Battery Energy Storage System (BESS), Thermal Energy Storage System (TESS). The community energy management system (CEMS) was operated to monitoring the community energy performance and energy trading of inner and outer community. This paper presents the positive energy performance and economic benefit of the proposed community. It was found that the proposed community has 229% of renewable energy penetration rate and about 30% of self-consumption rates can be improved compared with the conventional community.

Keywords: energy sharing community, electric and thermal energy sharing, self-consumption, BIPV

1. Introduction

Energy sharing community refers to the sharing of the surplus energy produced from distributed energy production systems with surrounding buildings in the community. Such energy sharing prevents the surplus energy from being supplied to the grid, thereby reducing the instability of the grid caused by renewable energy. In addition, the economic efficiency of distributed energy production systems can be secured through such energy sharing and trading even though there has been no economic benefit of surplus electricity for small-scale power generation.

2. Low-Carbon Energy Sharing Community

A low-carbon energy sharing community attempts to operate electricity and thermal energy supply chains at the same time. When prosumer buildings that produce surplus energy desire to sell surplus electricity, surrounding buildings that consume a large amount of energy purchase such surplus energy. In this instance, prosumers can sell either the surplus electricity produced from PV systems or the cold and hot energy produced using such surplus electricity. For such energy sharing/transactions, the real-time sales of energy to be produced are also possible, but energy is stored in energy storage facilities, such as energy storage systems (ESS) and thermal energy storage (TES), for sales at an appropriate time point

Figure 2 shows the conceptual diagram of the convergence energy system to obtain the optimal energy sharing effect by implementing an energy sharing platform. This convergence energy system consists of the power grid and cooling and heating networks. The electricity produced from the renewable energy systems installed in each building covers the electricity demand of each building, and the surplus electricity is supplied to the grid in the village. The surplus electricity is then shared with other surrounding buildings or stored in ESS for supply from ESS when the electricity produced from renewable energy is insufficient or the electricity cost of the grid is expensive. In addition, when ESS is fully charged with the surplus electricity, the heat pump is operated to store cold energy in summer and hot energy in winter in the heat storage tank for supply to each building.

The self-consumption rate of the convergence energy system for the community was analyzed using the load cover factor (LCF) and supply cover factor (SCF). LCF represents the proportion of the amount received from the grid (P_{imp}) to cover the power load (P_{load}), battery (P_{BESS}), and heat pump load for heat storage in the heat storage tank (P_{HP}). As it approaches 100%, it means that the proportion received from the grid is low (eq. 1). SCF represents the proportion of the amount transmitted to the grid (P_{exp}) after covering the power load (P_{load}), battery (P_{BESS}), and heat

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pump load for heat storage in the heat storage tank (P_{HP}) with the power generated from PV systems (P_{gen}). As it approaches 100%, it means that the proportion transmitted to the grid is low (eq. 2). In this instance, the power load includes all plug loads, such as lighting, in buildings. As these proportions approach 100%, the self-consumption rate becomes higher. In this study, the self-consumption rate (SLCF) was represented as the average of LCF and SCF (eq. 3).

The SCF is self-consumption, and that is defined as the fraction of the sharing the PV and BIPV generation power supplied to the load. High self-consumption and self-sufficiency means that the entire electricity load is mostly covered by the BIPV and PV. In this study, the self-consumption rate (SLCF) was represented as the average of LCF and SCF. In order to investigate the energy performance of the proposed system, the building load and BIPV was simulated by TRNSYS 18 software. This software provide hourly based dynamic simulation results.

$$LCF = 1 - \frac{\int_{t_1}^{t_2} P_{imp}(t)dt}{\int_{t_1}^{t_2}[P_{load}(t)+P_{BESS}(t)+P_{HP}(t)]dt} \quad \text{(eq. 1)}$$

$$SCF = 1 - \frac{\int_{t_1}^{t_2} P_{exp}(t)dt}{\int_{t_1}^{t_2} P_{gen}(t)dt} \quad \text{(eq. 2)}$$

$$SLCF = \frac{SCF+LCF}{2} \quad \text{(eq. 3)}$$

For the analysis of economic efficiency according to the energy cost, the following assumptions were made: Building residents purchased electricity at 100 won/kWh from the nano-grid operator and sold electricity at 50 won/kWh. In the economic efficiency analysis, the electricity cost was analyzed for energy sharing and trading with-out considering the initial cost for PV systems, ESS, and TES. In this paper, the initial cost of the systems has not been considered due to the fast change of subsidies for each systems.

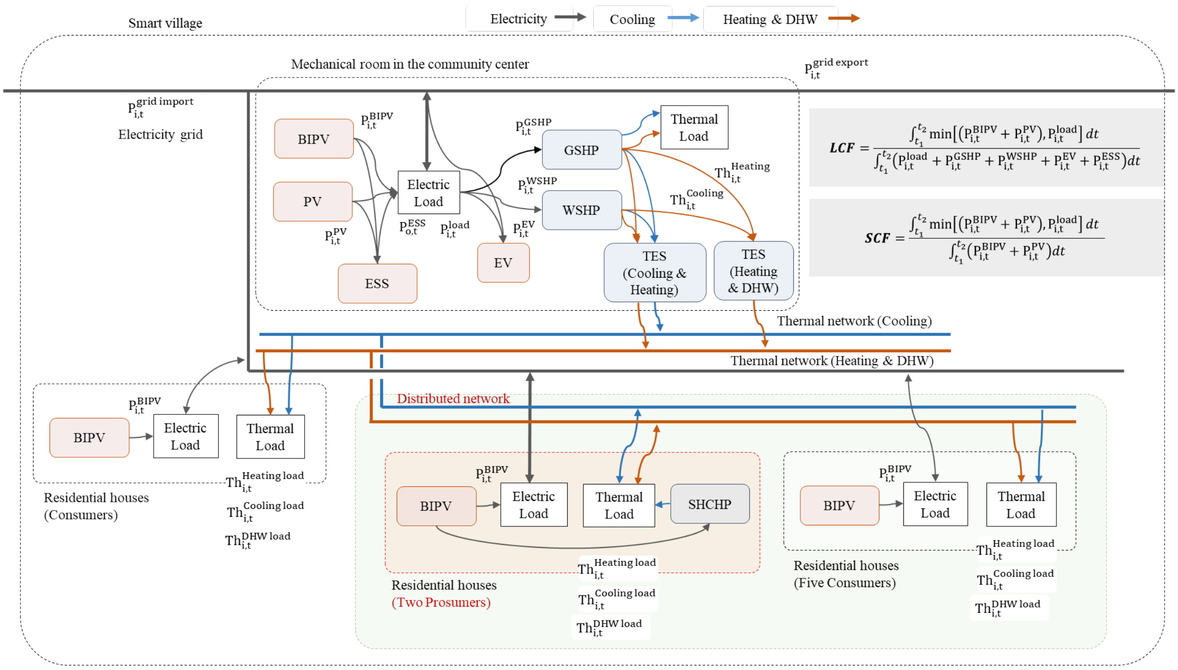

Fig. 1: Overview of conversion energy system

3. Case study: Smart Village

The smart village is located in the waterfront area of Busan Eco Delta City. It consists of 56 single-family houses and community facilities (Fig.2). It was designed with a site area of 7,202 m^2, a building area of 2,200 m^2, and a total floor area of 3,620 m^2. The single-family houses have two stories above the ground, and the community facilities have one underground story and two stories above the ground. The houses are lightweight steel structures based on the reinforced concrete structures, and the community facilities are reinforced concrete structures. The community facilities have a building area of 266 m^2 and a total floor area of 1,192 m^2. The single-family houses have a building area of 1,636 m^2 and a total floor area of 2,374 m^2 based on 19 houses. In the community buildings, locations where various renewable energy systems can be applied are roofs and walls. The building integrated photovoltaic system (BIPV) was installed on southern walls, and the installation area was 194 m^2. The building attached photovoltaic system (BAPV) was installed on roofs, and the installation area was 108 m^2.

First, the thermal load for each house was calculated to estimate building cooling and heating loads for the 19 houses. To this end, the number of household members was randomly assumed for each house, and the schedule for the thermal load was randomly calculated. As for the reference load, the thermal load profile was applied based on the measurement data and the random range was set to 80% based on this profile to derive the load profile. The reference thermal load was based on the use of the electricity of 3,500 kWh per year, and the 19 houses were set to have a load range from 2,574 to 5,064 kWh. The average load of the 19 houses was set to 3,582 kWh.

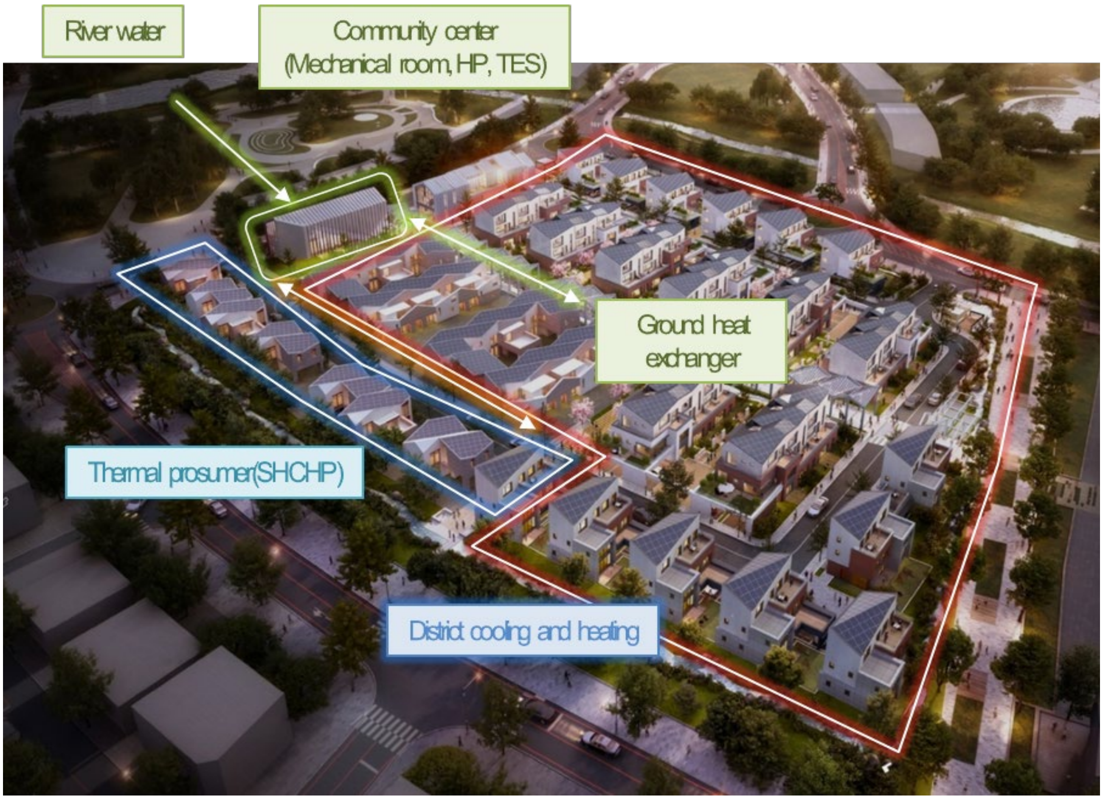

Fig. 2: Overview of smart village

4. Results

In Table 1 below, simple simulation analysis on the energy sharing improvement effect was conducted using the convergence energy system. SLCF and energy cost for the cooling period (June to August), intermediate period (March to May and September to October), and heating period (November to February) were compared between the energy transaction methods of P2G and P2P. They were also compared among the thermal energy system configurations of air-source heat pump (ASHP), central supply-type ground source heat pump (GSHP), and TES. In addition, energy performance according to the battery size was analyzed for each method.

The total capacity of the installed PV systems is 189.67 kW, and thus the total solar power generation is 220.2 MWh (Fig. 3). The total plug power consumption of buildings is 68.1 MWh. When ASHP is used, it consumes the power of 57.4 MWh. Thus, the total power consumption is 125.5 MWh, and the renewable energy penetration rate is predicted to be 180%. When GSHP is used, however, it consumes the power of 30.8 MWh and the renewable energy penetration is predicted to be 229%(Fig.4).

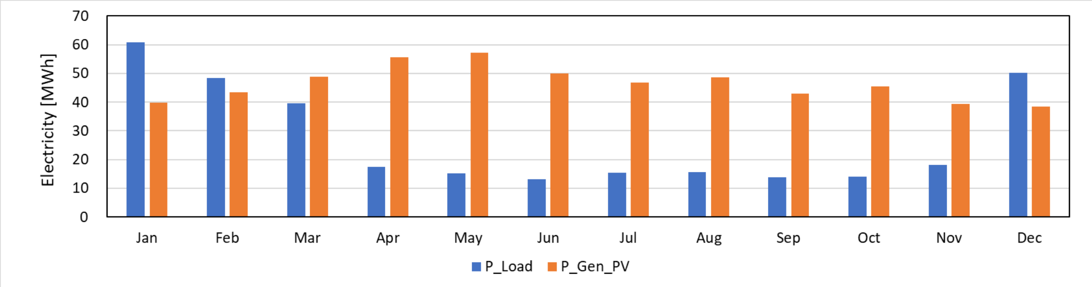

Fig. 3: Monthly power generation of BIPV and electric load

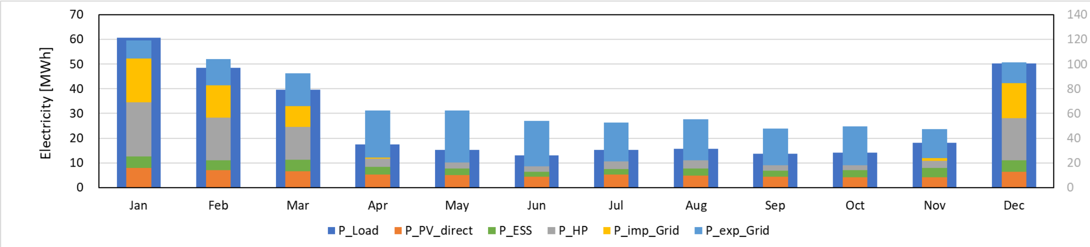

Fig. 4: Monthly power generation to ESS and heat storage

As shown in Table 1, the analysis results on seasonal and annual SLCF revealed that annual SLCF was 45.4% when energy sharing was not utilized due to P2G. When ASHP was used and energy sharing was applied, however, SLCF was 58.8% or higher. In addition, as the battery capacity increased, SLCF also increased from 58.8 to 77.5%. When central supply-type GSHP and TES were used, SLCF was more than 10% higher at the same battery capacity (100 kWh).

In terms of energy cost (Table 2), additional profits for surplus electricity could not be obtained for conventional P2G transactions. When cost benefits for surplus electricity are generated by supplying the energy produced through energy sharing to surrounding buildings and when surplus electricity is utilized using the central supply-type heat pump rather than using individual heat pumps, it was predicted that at least 2.5 million won can be obtained as a profit from the entire community. In addition, when both the battery and central supply-type heat pumps are applied, it was found that 6.5 million won per year and 340 thousand won per house can be obtained as profits for energy cost compared to the method of utilizing P2G.

Table. 1: Impact of system configurations for SLCF

Value	PV capacity [kW]	BESS [kWh]	Sum	Inter	Win	Annual
SLCF [%]	P2G, ASHP	0	48.2	45.0	43.8	45.4
	P2P, ASHP	100	63.30	59.6	54.5	58.8
		200	74.5	74.2	65.5	71.4
		300	79.5	78.4	75.0	77.5
	P2P, GSHP-TES	100	77.9	72.9	67.2	72.2
		200	79.5	77.5	83.6	80.0
		300	79.7	78.0	85.7	81.0

Table. 2: Impact of system configurations for cost

Value	PV capacity [kW]	BESS [kWh]	Sum	Inter	Win	Annual
Benefit cost [Mil.won]	P2G, ASHP	0	0	0	0	0
	P2P, ASHP	100	1.4	2.1	-0.9	2.7
		200	1.6	2.5	-0.5	3.5
		300	1.7	2.6	-0.3	4.0
	P2P, GSHP-TES	100	2.0	3.2	0.8	5.9
		200	2.0	3.2	1.0	6.3
		300	2.0	3.3	1.1	6.5

5. Conclusions

The cost benefits mentioned in this study are the simplest examples of various business models. Nano-grid operators will be able to contribute to the cost benefits of residents in the energy sharing community and create a new industry referred to as nano-grid operators by producing various energy costs. In addition, they can minimize the instability caused by introducing renewable energy systems at very high levels, such as for net-zero, through energy sharing. Basically, energy sharing and trading can maximize the utilization of energy sharing through harmony between prosumers and consumers. To practically achieve net-zero, however, it is necessary to maximize prosumers to enable net-zero in a community. In addition, it will be possible to improve cost benefits and the self-consumption rate by supplying renewable energy to buildings where it is difficult to achieve net-zero with prosumers.

6. Acknowledgments

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