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몽골의 가정용 PV-ES 하이브리드 시스템 개발을 위한 연구

The Study on Development of PV-ES hybrid system for Mongolian Household

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Abstract - In recent years, Ulaanbaatar, a capital of Mongolia has witnessed major problem that air quality reaches hazardous level during the winter season. Coal combustion for heating of every house in “Ger” district is main reason. One way to reduce the air pollution is mass usage of electric heater. However, there are several difficulties such as overload and degradation of transformers and other equipment used in distribution and transmission systems as well as power shortage occurrence in evening peak period due to residential consumption. This study aims to contribute for solving the air pollution and power shortage problem in Mongolia. One possible solution could be distributed generation (DG) with photovoltaic (PV) penetration. In this study, PV with energy storage (ES) hybrid system to reduce peak load is analyzed. We proposed the suitable structure of PV-ES hybrid for Mongolian household, and suggested several operation scenarios. Optimal operation algorithm is carried out based on a comparison aspect from economical, grid impact and PV penetration possibility. The economic analyse shows annual income of 520USD, and has a payback period of 8 years for selected scenario. The proposed PV-ES system structure is verified by experimentation set on the building rooftop in city center. The suggested scenario is planned to apply for system in further research.

Key Words : Photo voltaic system, Energy storage system, Peak load cutting, Air pollution,

1. Introduction

For capital Ulaanbaatar of Mongolia, where has encountered several challenges which are mentioned as: population growth[1], air and soil pollution[2], wrong planning of city and power shortage[3]. Especially, air pollution of Ulaanbaatar city has become the main problem of every citizen living in the capital[4]. City government is carrying out the projects towards to the smokeless stove, improved fuel for combustion, electric heater, discounted tariff for ger district area [2, 3]etc. However, it has not currently achieved enough improvement [5, 6].

Daily electric energy consumption fluctuates depending on demand that peak load occurs during evening time and in midnight power curve reaches at minimum value related to the household usage features[7]. Peak load of power in winter time exceeds total installed capacity of national energy sources. At this moment, energy shortage is imported from Russia with the high price. But surplus electricity is produced during the night, because of poor controllability of coal fired combined heat power station, it is exported back to Russia with low price[8].

According to the COP21, otherwise Paris agreement to set a goal of limiting global warming to "well below 2˚C" per year was mentioned that countries should increase utilization of not only centralized large scale but also small sized distributed renewable sources[9]. High penetration of residential intermittent sources such as solar and wind, energy storage is required. An energy storage devices such as batteries could be considered in order to compensate for mismatch between the generation and demand curve and also to improve peak load cutting effect[10~13].

PV-ES hybrid system has been studied with the viewpoint of structure, sizing and optimization. Specially circuit topology, control algorithm for battery charger, maximum power point tracking(MPPT) converter for PV and grid connected inverters are considered in several studies[14, 15].

Thus, we proposed the possible solution as PV-ES hybrid system to provide the residential consumption in Mongolia. The system aims to achieve economic benefits by the way to reduce the peak load of utility grid and shaving the consumption graphics based on the PV production with

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residential feature.

In this study, three different operation sequences are suggested for PV-ES hybrid system for Mongolian residential. Section 2 presents a detailed description of the PV-ES hybrid system such as energy consumption of household, structure of system, operation scenarios. Comparison with the different operation scenarios are included in the same section, grid impact and the economic benefit are also discussed. Section 3 presents the verification of operation and structure for PV-ES hybrid system based on long term experimentation of pilot system. While Section 4 summarizes the derived conclusion.

2. Proposed PV-ES hybrid system

2.1 Energy consumption of Mongolian household

Due to less development of industry part, the load characteristic of Mongolian energy system is dependent on residential consumption. In Fig. 1, seasonal load profile of household is illustrated. During the period of 18:00~22:00 peak load, 01:00~06:00 lower consumption is occurred, respectively. Because of heating load in winter season energy consumption is higher.

We analyzed energy consumption of household in ger district using data of more than 30 thousand consumers from electrical distribution company. In Fig. 2 energy consumption histogram of consumers is illustrated. We classified total households into 3 parts as lower (lower than 2000kWh), middle (2000~2500kWh) and high consumption part (above 3000kWh), accounting 30%, 44%, and 26%, respectively. We considered that PV-ES hybrid system is suitable for the household with high energy demand which have shown as Fig. 3.

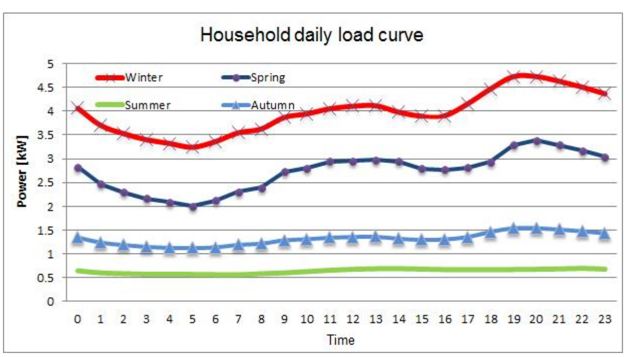


Fig. 1 Seasonal load graphic of the chosen object

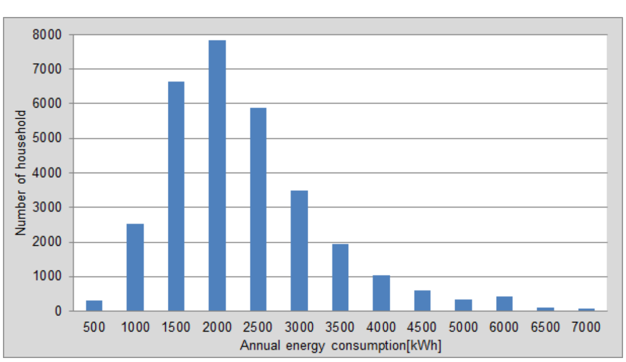


Fig. 2 Annual consumption histogram of consumers

2.2 PV-ES hybrid system structure

The structure of PV-ES hybrid system and positive power flow are presented in Fig. 4. It consists of unidirectional dc/dc converter for PV array with MPPT function, bidirectional dc/dc converter for battery charge/discharge control and bidirectional dc/ac inverter for utility interconnection. When battery is charged, bidirectional dc/dc converter operates as buck mode, otherwise as boost mode.

The rated power of PV-ES hybrid system is adjusted for the consumption of household with high demand.

Sizing for each component is optimized for averaging

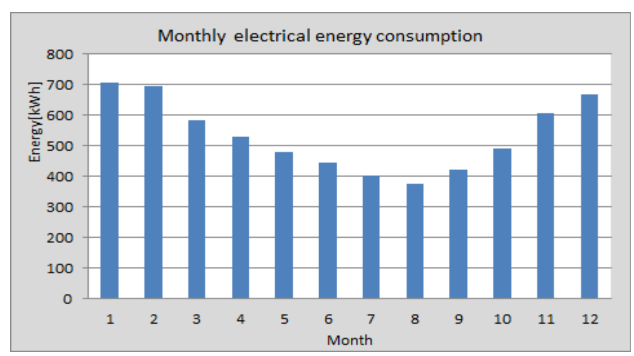


Fig. 3 Monthly averaged energy consumption of household with high demand

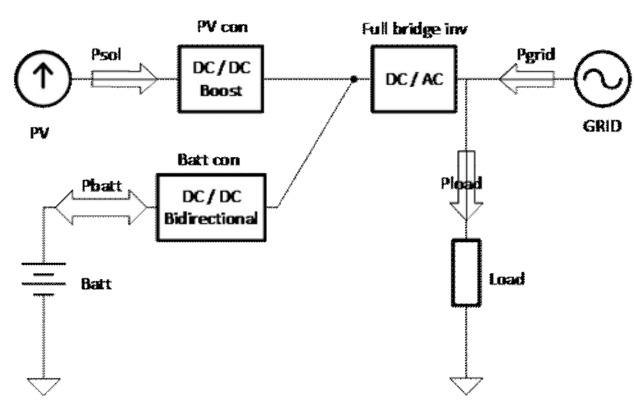


Fig. 4 Structure and power flow direction of system

daily grid power in winter. Specification of each component is chosen as shown in Table1. We assumed the depth of discharge(DOD) of battery as 50% and corresponding equation is shown in (1). Sizing of the PV array is also depended on energy demand. We assumed capacity factor(η) of PV as 15% and generated energy from PV(E_{PV}) could cover 50% of household consumption in winter and equation is shown in (2). Power rating for PCS meets with peak power demand of household.

2.3 Operation Scenario and analysis

Scenario-1

This scenario shows operation of conventional grid tied PV system that generated energy from PV is directly injected to grid. Otherwise system does not have ES for this scenario. The seasonal operation graph of the system under scenario 1, which consists of daily household load, PV generated and grid power curves shown in Fig. 7. PV generation time mismatches with residential peak load period (18:00~22:00) so the system haven't enough significance for the grid. It's clear that scenario is not suitable for grid impact.

Scenario-2

In this scenario, PV generated energy is stored in battery, except for the peak-cut time interval and inverter can be stopped. While peak load occurring, stored energy in battery is supplied to the load with constant value and contribute to grid load reduction. The operation sequence for this scenario is shown in Fig. 5.

For the state 1, battery is being charged, and it continues till 18:00. When battery is fully charged(>9kWh), excess energy of PV is supplied to load. About state 2, it demonstrates operation for peak load period. Battery discharges with constant value of 900W. We decided the DOD as 50% and it means that discharging operation stops when battery SOC reached at 4.5kWh.

In this scenario, the drawback is peak power cutting effect depends on the PV generation. Particularly, in hazy weather, ES could not been charged and it causes failure, peak cut effect for the grid.

Table 1 Specification of PV-ES hybrid system

#	Component	Specification
1	PV array	3.8kW, 16series connected modules
2	PCS	5kW, 1 pack including MPPT converter, Battery charger and grid tie inverter
3	Battery ES	9kWh lead acid batteries

The seasonal operation graph of the system under scenario 2 shown in Fig. 8 and it's clear that power shaping function can be performed assist with battery.

$$E_{ESS} = E_{demand} / M_{DOD} \quad (1)$$

$$P_{PV} = \frac{E_{PV}}{\eta \cdot 24h} \quad (2)$$

$$P_p = E_{req} / T_{\min} \quad (3)$$

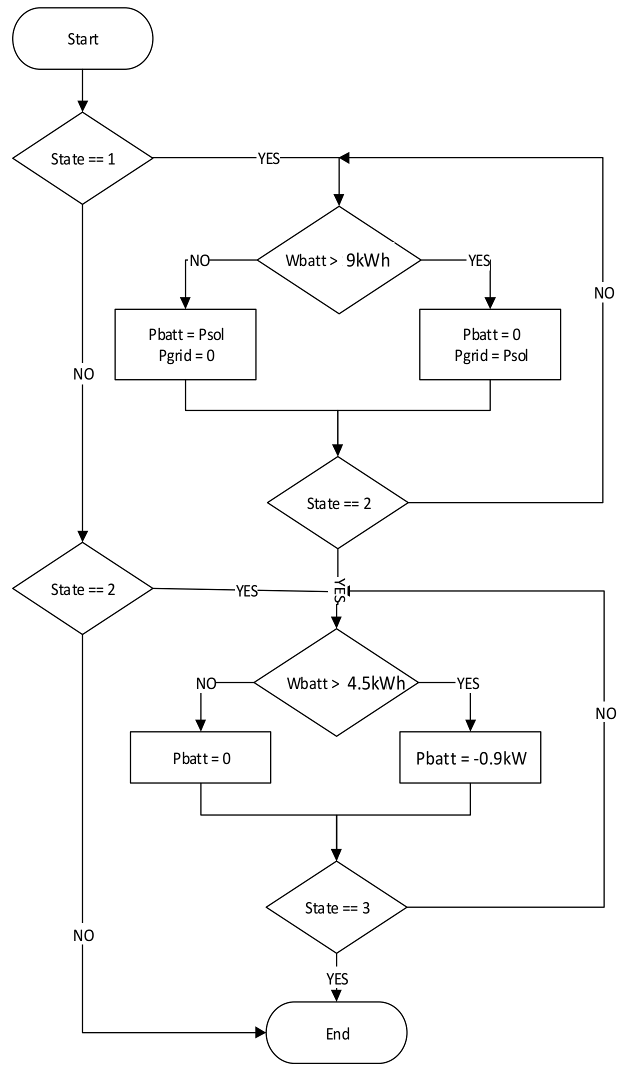


Fig. 5 Operation sequence for Scenario 2

Scenario-3

In this scenario, PV generated energy is directly supplied to load like scenario 1 and battery is charged by utility during the night differently from scenario 2. During the peak load period, stored energy in battery is injected to the load with constant value.

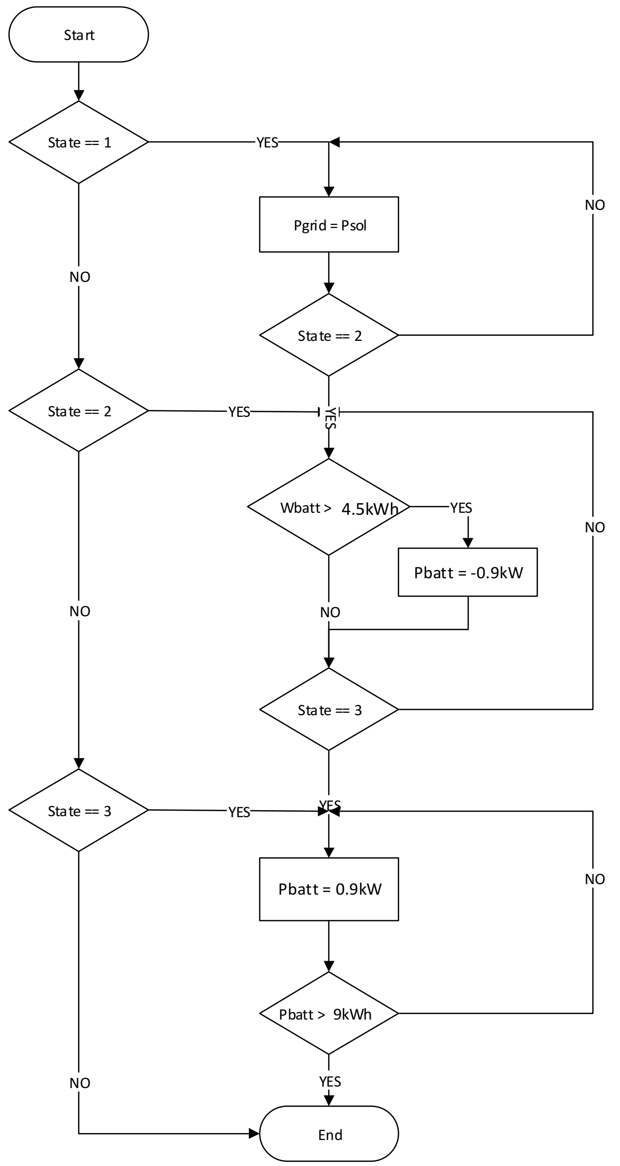


Fig. 6 Operation sequence for Scenario 2

Fig. 6 shows the operation sequence corresponding to this scenario. In state 1, PV-ES hybrid system operates like conventional grid connected PV system without battery, which covering from sunrise to start of peak load period (18:00). About state 2(18:00~22:00), operation sequence is same as state 2 in previous scenario, shortly discharging operation continues with constant power of 900W until battery SOC reaches at 4.5kWh. As for state 3, battery is charged by bidirectional dc/ac inverter from grid during the night time till fully charged with constant value of power (900W).

The seasonal operation graph of system with this scenario shown in Fig. 9. Consuming the night time electricity for battery charging is no worse affect to the grid because it has lower load. Even so, battery charging by reliable source prevents peak cut effect failure for grid and drawback above can be solved.

2.4 Operation Scenario and analysis

In this section, annual profit, peak load reduction and averaging effect for daily load curve are analyzed. Net present value(NPV) and internal rate of return(IRR) of PV-ES hybrid system is calculated as (4), (5). The result of economic analyze is listed in Table 2.

Table 2 Economic evaluation on each scenario

Number of Scenario	Annual income USD)	IRR (%)	NPV (USD)	Payback period
1	317.4	10.1	240.1	8
2	438.5	8.7	374.4	9
3	544	10.4	333.3	8

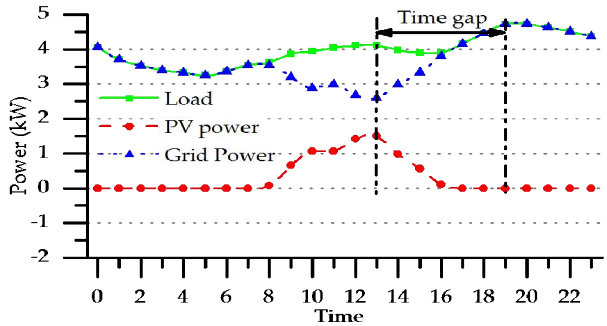
Table 3 Grid load reduction of each scenario

#	Description	Winter	Spring	Summer	Autumn
Sc1	Night time	0.0	0.0	5.1	0.0
	Daytime	17.3	60.5	233.5	69.7
	Evening time	0.0	0.2	4.2	0.0
Sc 2	Night time	0.0	0.0	0.0	0.0
	Daytime	9.4	54.1	204.6	58.0
	Evening time	15.6	22.6	109.7	47.7
Sc3	Night time	-15.5	-23.7	-88.4	-46.2
	Daytime	19.4	63.5	246.1	76.0
	Evening time	15.6	22.6	109.7	47.7

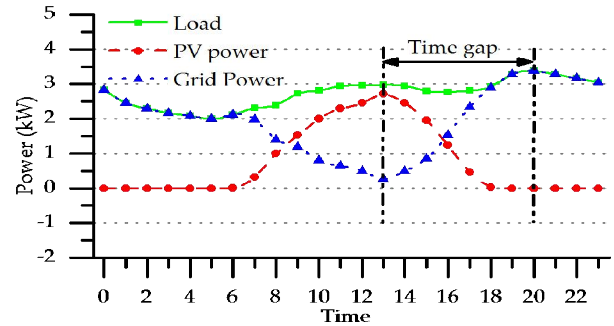
The grid load reduction in each duration is expressed as equation (6) and result is shown in Table 3. The reduction of daily power variation, otherwise grid load averaging effect is calculated as (7). From the comparison between three operation sequences, scenario 3 has been selected for proposed system, most suitable one for Mongolian household feature.

$$NPV = \sum_{t=1}^{N} \frac{E_t - C_t}{(1+r)^t} - C_0 \qquad (4)$$

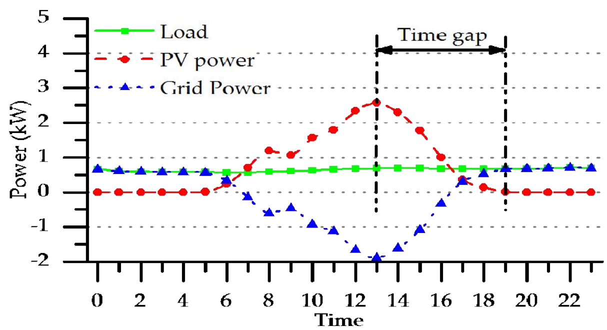
Herein: E_t-annual income, C_t-annual outcome
r-interest rate, t-year index,
C_0-initial investment



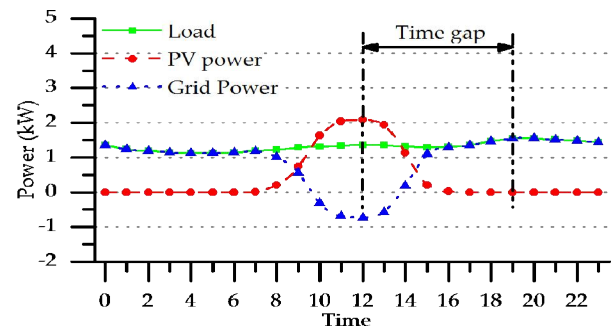
(a) Winter operation curve



(b) Spring operation curve

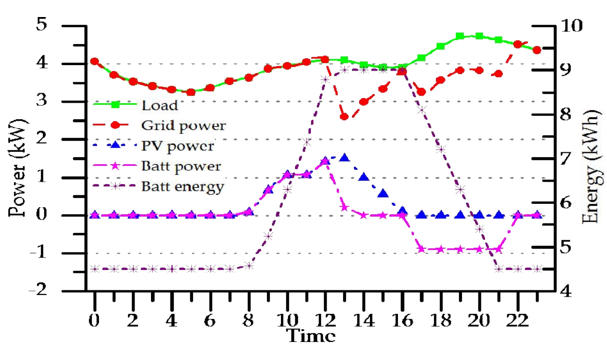


(c) Summer operation curve

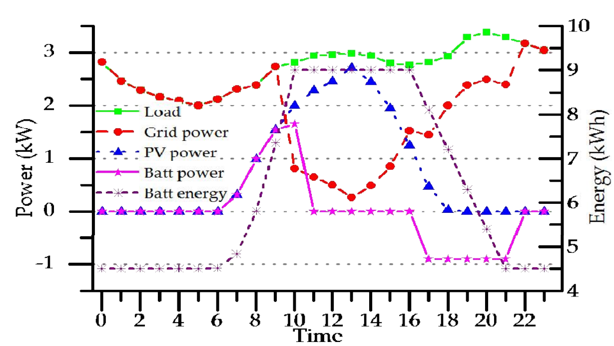


(d) Autumn operation curve

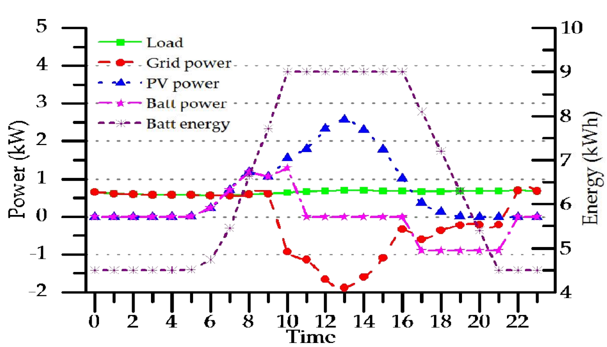
Fig. 7 PV-ES hybrid system operation curve in scenario 1



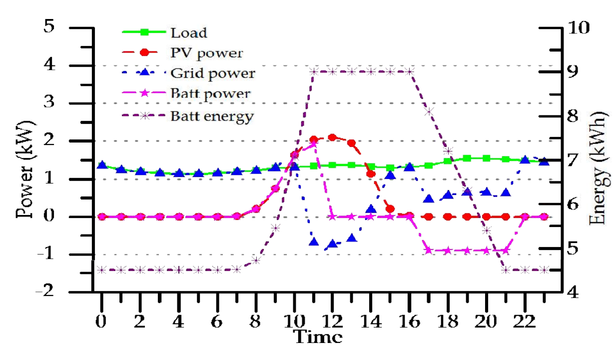
(a) Winter operation curve



(b) Spring operation curve

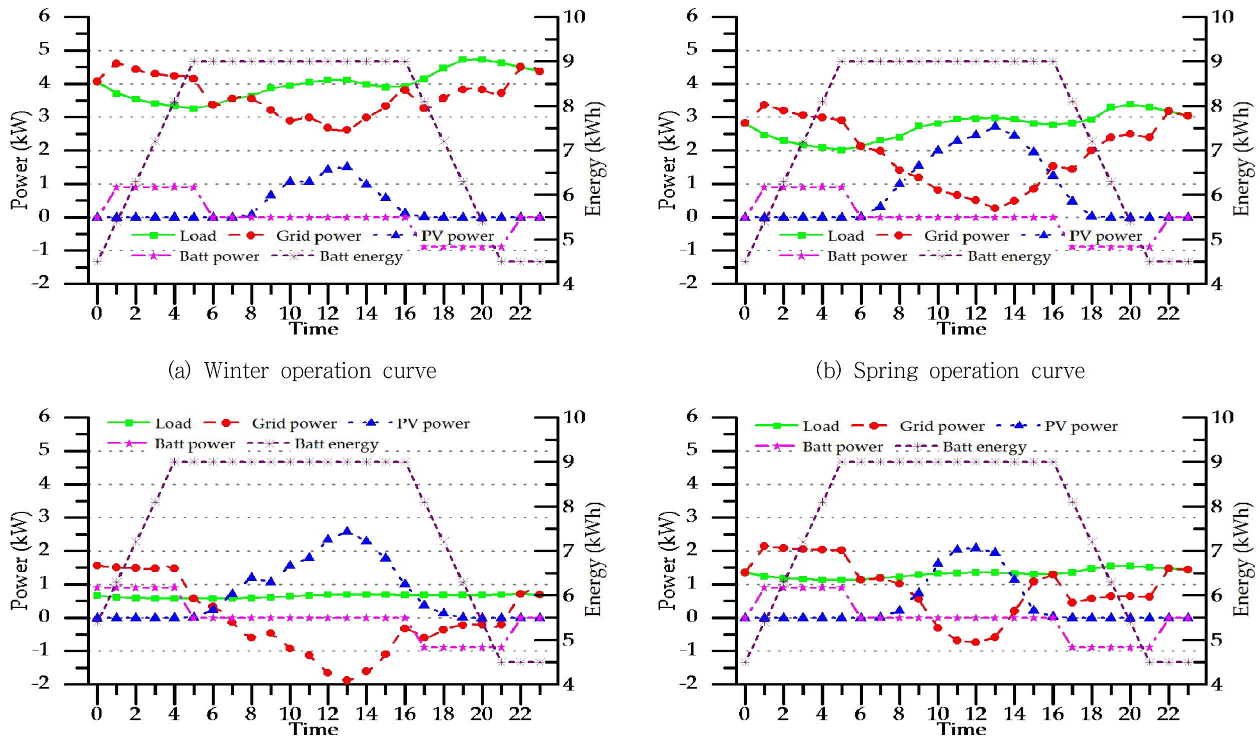


(c) Summer operation curve



(d) Autumn operation curve

Fig. 8 PV-ES hybrid system operation curve in Scenario 2



(a) Winter operation curve

(b) Spring operation curve

(c) Summer operation curve

(d) Autumn operation curve

Fig. 9 PV-ES hybrid system operation curve in Scenario 3

$$IRR = r_a + \frac{NPV_a(r_b - r_a)}{NPV_a - NPV_b} \tag{5}$$

Herein: r_a-lower discount rate,

r_b-higher discount rate,

NPV_a-NPV using the lower discount rate,

NPV_b-NPV using the higher discount rate,

$$\triangle E = \frac{\int_{t_1}^{t_2}(P_{grid} - P_{load})dt}{\int_{t_1}^{t_2} P_{load} dt} \cdot 100\,[\%] \tag{6}$$

Herein: t_1, t_2 are start and end time of each duration,

$$\triangle P_{daily} = \frac{(P_{grid.\max} - P_{grid.\min})}{P_{grid.avg}} \cdot 100\,[\%] \tag{7}$$

3. PV-ES hybrid system experimentation

In order to verify PV-ES hybrid system structure and operation, we installed system with specification mentioned in Table 1. For the load selection in installed system, public area lightening of building in city center was chosen.

3.1 PV Array

We used the mono-crystalline PV module marked c-Si M 60 EU 30123 that manufactured in Bosch industry in Germany, which has a rated power of 240W. In total, 16 modules connected by series thus open circuit voltage of this array is 598V, maximum power point (MPP) voltage is 480V. Fig. 10 shows the real appearance of installed system on the rooftop.

3.2 Power conversion unit

We used power conditioning system(PCS) which is manufactured in Netherlands, and model number is PR50SB-BS/S240. This kind of router is suited with industry and has some functions that are adapted with solar power technology.

3.3 Battery

For the pilot project, we used 9kWh lead acid battery storage. Charge controller for battery is included in PCS.

However, the usage of the battery is considerably compact, but it is effective to lifecycle which battery has low lifetime compared to the other component of the system. Consumer should decide charge and discharge time and DOD for system adjustment.

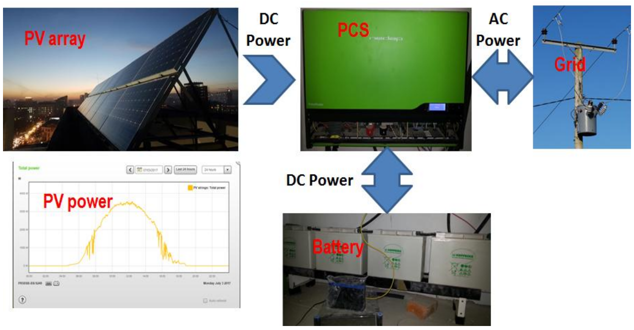


Fig. 10 PV-ES hybrid system installation

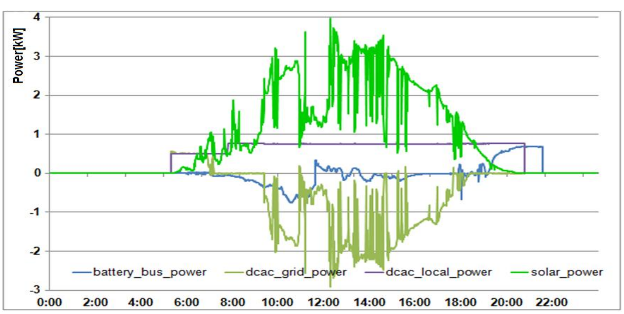


Fig. 11 PV-ES hybrid system experimentation result

4. Conclusion

In this paper, PV-ES hybrid system to peak load shifting for Mongolian households and its optimal system structure as well as operation sequences are proposed and compared. The grid load reduction is possible by using ES. Differently from the conventional PV system, the proposed system reduces the peak electrical power demand of grid for evening. The proposed PV-ES hybrid system is holding 3 kW power output and ES of 9 kWh. Evaluation of the economic feasibility was done with operation year of 25 years, 8 year payback period and initial investment about 2500USD as well as it has income from daily production. In addition, the pilot system was not satisfactory cause of the inverter is not controllable as proposed operation. The experimentation result indicates that proposed hybrid system could have an impact on electrical grid in positive way especially with consumption feature of urban area.

For further study longer operational experience and data would be needed to make the PV system apply to the actual utility as a peak load shifting.

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