Comparative Study of Battery Storage and Hydrogen Storage to Increase Photovoltaic Self-sufficiency in a Residential Building of Sweden

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Abstract

Photovoltaic (PV) is promising to supply power for residential buildings. Battery is the most widely employed storage method to mitigate the intermittence of PV and to overcome the mismatch between production and load. Hydrogen storage is another promising method that it is suitable for long-term storage. This study focuses on the comparison of self-sufficiency ratio and cost performance between battery storage and hydrogen storage for a residential building in Sweden. The results show that battery storage is superior to the hydrogen storage in the studied case. Sensitivity study of the component cost within the hydrogen storage system is also carried out. Electrolyzer cost is the most sensitive factor for improving system performance. A hybrid battery and hydrogen storage system, which can harness the advantages of both battery and hydrogen storages, is proposed in the last place.

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Keywords: photovoltaic; battery storage; hydrogen storage; genetic algorithm

1. Introduction

The Photovoltaic (PV) electricity accounts only for 0.06% of total electricity consumption in Sweden [1]. Some important reasons attribute to the local weather condition, low incentive, intermittence and the seasonal mismatch of PV production. The intermittence of PV generation is usually mitigated by energy storages, which in most cases are batteries. However, battery storage contributes little to the seasonal mismatch because of high expense and inability for long-term storage [2]. Hydrogen storage system comprises of electrolyzer, hydrogen tank and fuel cell. It has lower round-trip efficiency. However, it is suitable for addressing the seasonal mismatch problem, because it is capable of storing the excess electricity in the form of hydrogen for long period.

In this study, the comparisons between battery storage and hydrogen storage under different PV capacities are carried out. Genetic Algorithm is employed to solve the multi-objective problem concerning achieving high Self Sufficiency Ratio (SSR) and high Net Present Value (NPV). A sensitive study is also conducted to investigate the influence of component costs on the system SSR-NPV relationship. A hybrid battery and hydrogen system is also proposed.

2. Methodology

2.1. System configuration and simulation

Schematic diagram of the studied system is shown in Fig. 1. Either battery storage or hydrogen storage will be employed. NPV and SSR are calculated by equations 1 and 2, respectively.

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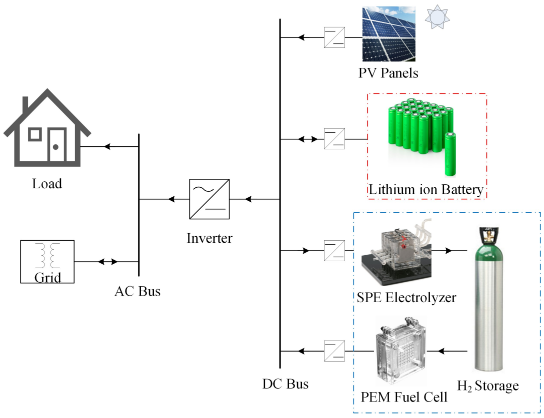

Fig. 1. Schematic diagram of PV-battery and PV-hydrogen System

$$NPV = \sum_{y=1}^{25} \frac{(R_y - C_{OM,y} - C_{R,y})}{(1+d_r)^{y-1}} - Inv \quad (1)$$

$$SSR = \left(1 - \frac{\int_{t_1}^{t_2} G(t)}{\int_{t_1}^{t_2} L(t)}\right) \times 100\% \quad (2)$$

R_y, $C_{om,y}$, $C_{R,y}$ are revenue, O&M cost, replacement cost at year *y,* respectively. *Inv* is the investment cost. d_r is the discount rate (2%) [3]. The revenue is the sum of deferred retail purchases (Price: Elspot price plus 0.84 SEK/kWh [4]) from the grid and wholesale electricity (Price: Elspot price [1]) sold to the grid. Information related to the cost of different components can be found in Table 1.

The simulation of the system is carried out in Matlab R2015a environment.

2.2. Load and weather profile

The hourly load profile in 2014 (644 MWh) of a residential building (Gothenburg; N57.70°, W11.98°) is used as study case (data from Wallenstam AB). The weather data is taken from Meteonorm [5].

Table 1 Component costs, lifetimes, and O&M costs

Component	Cost	Life Time	O&M	Reference
PV Panels	12900 SEK/kW	25 Years	1%	[1]
Fuel Cell	33840 SEK/kW	30000 Working Hours	0.5%	[6]
Electrolyzer	42300 SEK/kW	15 Years	0.5%	[6]
Hydrogen Tank	4822 (SEK/kg)	15 Years	0.5%	[6]
Lithium ion battery	3966 SEK/kWh	746 @ 80% DOD	0.5%	[7]

2.3. The Photovoltaic panel model

Single diode five parameter model is used in the study. The Current-Voltage curve of the PV module (SUNTECH STP255-20/Wd) is described in equation 3 [8]. The azimuth and tilt angles are 0° and 36°, respectively, which ensure the maximal yearly production.

$$I = I_l - I_l \left[e^{\frac{V+IR_s}{a}} - 1 \right] - \frac{V + IR_s}{R_{sh}} \quad (3)$$

2.4. Lithium ion Battery model

Improved shepherd Battery Model [9-11] is employed in this study. The charging and discharging characteristics are represented by equations 4 and 5, respectively.

$$V = E_0 - K\frac{Q}{Q-\int it}\cdot i^* - K\frac{Q}{Q-\int it}\cdot\int it + Ae^{(-B\cdot\int it)} - iR \tag{4}$$

$$V = E_0 - K\frac{Q}{0.1Q+\int it}\cdot i^* - K\frac{Q}{Q-\int it}\cdot\int it + Ae^{(-B\cdot\int it)} - iR \tag{5}$$

Battery life depends on the working conditions. The SOC (State Of Charge) variation of the battery is converted to the standard cycles through the Rainflow counting method to estimate the battery lifetime [12, 13]. The lifetime parameter is taken from Wang et al [7].

2.5. Hydrogen storage model

The Solid Polymer Electrolyte (SPE) electrolyzer produces hydrogen (20 Mpa with built-in compressor) from electricity. The power-current (P-I) curve (Fig. 2.) with consideration of compressor power is obtained from Li et al [14]. Polymer electrolyte membrane (PEM) fuel cell produces electricity from hydrogen. Its power-current (P-I) curve (Fig. 2.) is obtained from product data [15].

3. Results and Discussion

3.1. Comparison between battery storage and hydrogen storage

The comparisons between battery storage and hydrogen storage are carried out under PV capacities of 100, 200 and 300 kW_p. The battery capacity is increased from 50 kWh to 800 kWh with the interval of 50 kWh. The relationship between the NPV and SSR is shown in Fig. 3 (red). The optimal sizing of the components in the hydrogen storage system is achieved with multi-objective genetic algorithm, which presents the relationship between SSR and NPV in the form of Pareto front (Fig. 3, blue). The SSR-NPV relationship without storage is also shown (Fig. 3, black). The battery storage has better performance than the hydrogen storage. Under the same NPV, battery storage achieves higher SSR than the hydrogen storage, and the SSR difference increases with the decrease of NPV.

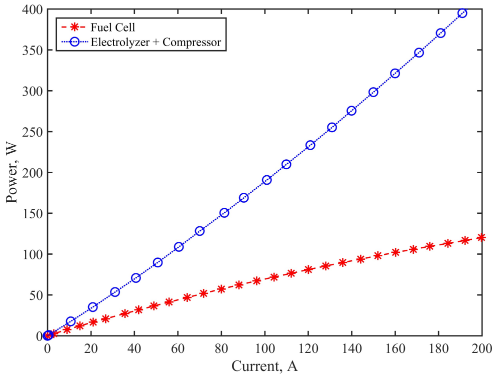

Fig. 2. Single cell P-I curve for fuel cell and electrolyzer

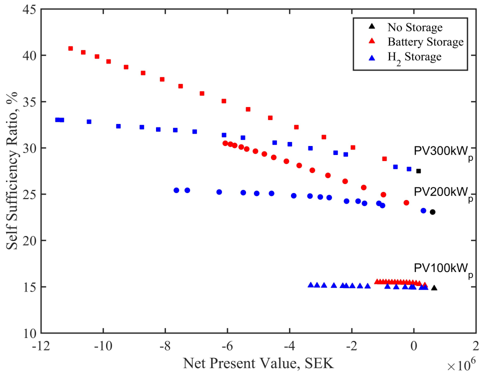

Fig. 3. SSR vs. NPV of battery storage and hydrogen storage

3.2. Sensitivity study of the component cost in the hydrogen storage system

The prices for the fuel cell, electrolyzer and hydrogen tank are decreased to 75%, 50% and 25% of the current price, respectively. The Pareto front of each scenario (PV 200 kW_p) is presented in Fig. 4.

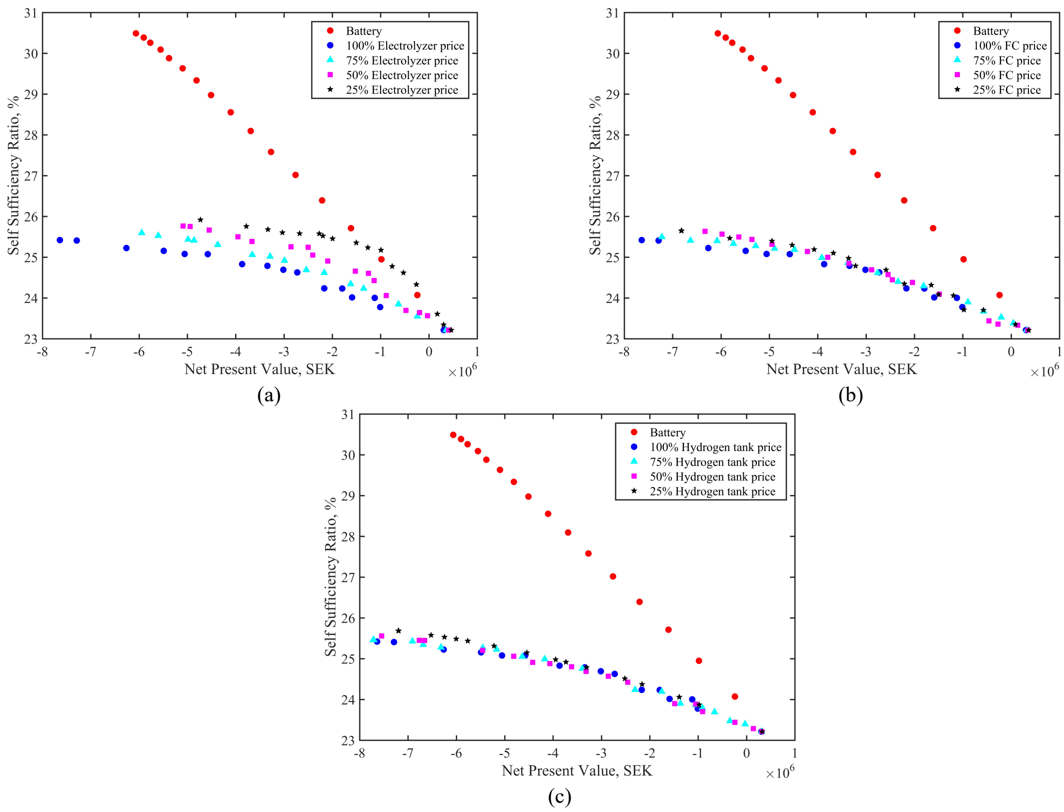

Fig. 4. Sensitivity study of the component cost on SSR-NPV relationship
(a)Electrolyzer cost; (b) Fuel cell cost; (c) Hydrogen storage cost

The Pareto fronts with either decreased fuel cell price or decreased hydrogen tank price are twisted with the Pareto front with current prices. It is indicated that the fuel cell price and hydrogen tank price are not sensitive in improving the system performance regarding NPV and SSR. The decreased electrolyzer price can improve the system SSR under the same NPV. It is also found that only when the electrolyzer price decreased to 25% of the current price, the hydrogen storage system could compete with the battery storage, achieving similar SSR at high NPV.

3.3. Hybrid battery and hydrogen storage system

Battery storage has lower capital power cost and higher round trip efficiency, while hydrogen storage has lower capital energy cost and longer storage period. A hybrid battery and hydrogen storage system is proposed and compared with single battery system and single hydrogen system. As shown in Fig. 5, the three systems have similar SSR at positive NPV conditions; while with the decrease of NPV, the hybrid system has much higher SSR than the other two systems.

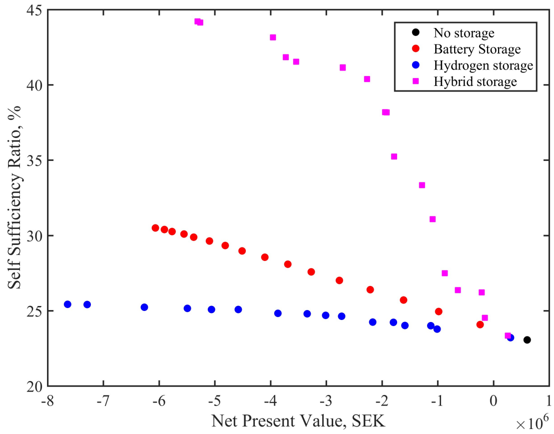

Fig. 5. Comparison between hybrid storage system with single battery or hydrogen storage system

4. Conclusions

The comparison between battery storage system and hydrogen storage system indicates that battery storage system is superior to the hydrogen storage system regarding NPV and SSR. Battery storage system achieves higher SSR under the same NPV than hydrogen storage system, and the SSR difference between two systems increases with the decrease of NPV. The sensitivity study on the component cost of the hydrogen systems indicates that the electrolyzer cost is the most sensitive factor for improving the SSR and NPV. It is also found that only when the electrolyzer price drops to 25% of current price, the hydrogen storage system can have similar SSR with battery storage system under high NPV. The proposed hybrid battery and hydrogen storage system can take advantage of both the individual battery and the individual hydrogen storage systems. It increases SSR compared with individual battery or hydrogen storage system under the same NPV.

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Biography

Yang Zhang is a Ph.D. student in KTH-Royal Institute of Technology. His research focuses on the integration and optimization of energy storage with microgrid.